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ECONOMIC CONSEQUENCES OF AN ODWO FOR TRITIUM

Economic Services Branch
Ministry of Environment and Energy
December 1994

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1. INTRODUCTION & BACKGROUND

This report provides economic analyses of the consequences of alternative options for setting an Ontario Drinking Water Objective (ODWO) for tritium.

The Ministry of Environment and Energy has developed an interim Ontario Drinking Water Objective (ODWO) for tritium and has released a *Rationale Document for the Development of an Interim Ontario Drinking Water Objective for Tritium* (Ref #1). The Ministry recommends that the tritium objective be set at 7,000 becquerels/litre (Bq/L) to replace the current objective of 40,000 Bq/L.[1] This objective is based on the most recent World Health Organization drinking water guideline. The same objective has been adopted by Health Canada (Ref #2) for drinking water across Canada.

The Advisory Committee on Environmental Standards (ACES) reviewed the Ministry's Rationale Document, received written public comment on it and other MOEE documentation, held public hearings and issued its own report, *A Standard for Tritium - A recommendation to the Minister of the Environment and Energy, May 1994* (Ref #3). ACES has recommended an ODWO for tritium of 100 Bq/L for a Maximum Acceptable Concentration in drinking water with further reduction to 20 Bq/L after 5 years.

ACES further recommended that, wherever tritium in drinking water exceeds the 100 Bq/L or the 20 Bq/L, an alternate water supply should be provided.

The Minister has publicly announced that he will make a decision on the matter in the fall, after considering the socio-economic and other relevant implications.

The purpose of this report is to:

- ☞ List past and current concentrations of tritium at water treatment plants (WTP) near nuclear facilities which are the main sources of tritium in drinking water supplies;
- ☞ Describe the current discharges of tritium from nuclear plants;
- ☞ Calculate the doses and health risks associated with present concentrations of tritium in drinking water to populations that receive drinking water from these WTP;
- ☞ Describe the types of actions that are being taken and that can be taken to reduce exposure to tritium in drinking water to levels corresponding with different options for an ODWO;

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[1] Becquerel (Bq) is the international unit of measurement of radioactivity. One becquerel equals one atomic disintegration per second and is directly proportional to the quantity of radioisotope.

- ☞ Estimate the costs and reduced levels of tritium associated with those actions; and

- ☞ Describe the risk reduction benefits associated with a lower ODWO in terms of reduction in human health risk.

While this assessment focusses on the economic consequences of a revised ODWO for tritium, adopting ACES' recommendations has significant repercussions for sources and media of radiation beyond an ODWO for tritium.

In a letter to Ministry staff dated August 9, 1994, Dr. E.G. Letourneau of Health Canada indicates that,

> *"if the ACES recommendation were adopted by the province of Ontario...the allowable dose levels from tritium would be much lower than exposures encountered from other radionuclides in other parts of the province, such as natural radioactivity in well water supplies, cesium-137 and polonium-210 in fish and caribou meat and radon in homes and well waters."*

In their August 23/94 submission to the Minister, Energy Probe (Ref #4) acknowledged that,

> *"the largest socio-economic impact of the ACES recommendations is that those recommendations --- especially if implemented --- will set a precedent for future decisions in Ontario and elsewhere concerning acceptable public exposures to radioactive pollution.(page 15)"*

The economic consequences of these further effects could be larger than those of tritium standards for drinking water. These implications are addressed briefly in Section 11 (page 32).

2. IMPLICATIONS OF ONTARIO DRINKING WATER OBJECTIVES

2.1 Purpose of Ontario Drinking Water Objectives

The primary purpose of ODWOs are to protect public health. ODWOs are defined by a Maximum Acceptable Concentration and an averaging time. Concentration objectives are called Maximum Acceptable Concentrations (MACs). The economic implications of setting an ODWO depend on the level of the MAC, the averaging time chosen and the actions required when it is exceeded.

According to the ODWO Grey Book (Ref #5) the MAC is a health-related objective established for parameters which have known or suspected adverse health effects. The length of time the MAC can be exceeded without injury to health will depend on the nature and concentration of the contaminant. In the event that a MAC is exceeded in drinking water the local Medical Officer of Health (MOH) must be notified who then decides, in consultation with other agencies what further actions should be taken. Ultimate judgements regarding human health issues are made by the local MOH under the legislative authority of the Health Protection and Promotion Act.

According to the point 8.3 in the Ministry's Rationale Document (Ref #1), "They (Ontario Drinking Water Objectives) provide guidance as to the acceptability of public drinking water supplies and water supplies that meet these objectives are protective of human health" (page 15).

For radionuclides, the ODWO Grey Book (Ref #5) states:

> *Radionuclide concentrations that exceed the MAC may be tolerated for a short duration, provided that the annual average concentrations remain below the MAC and the restriction for multiple radionuclides is met.* (page 14)

and

> *If the MAC is exceeded, the water should be immediately resampled. If any result in the resampled water exceeds its MAC, then the MOH and the MOEE should be notified and the monitoring frequency designated by the District Officer shall continue in order to define the source. Monitoring should be continued until the problem has been eliminated.* (page 28)

Consequently, the economic implications of setting a MAC principally result from exceedences of annual average concentrations, however, there are also implications if concentrations in weekly samples exceed the MAC through the cost of sampling, the notification process and the level of public concern.

2.2 Implications for Tritium Discharge Sources and Municipalities

With respect to the removal of tritium from water supplies, the Ministry cites references in its Rationale Document (Ref #1) which state that conventional water treatment technologies have not been proven to remove tritium from water.

According to the CCME Canadian Drinking Water Guidelines (Ref #6),

> *Readily available information on drinking water treatment for removal of radionuclides is limited and primarily confined to Radon* [and Radium]. *Because of the characteristics of the elements, conventional coagulation and flocculation processes are of variable effectiveness for soluble isotopes (p.1-19)."*

While certain other types of treatment technologies might be effective in reducing tritium in drinking water, they have not been studied sufficiently to determine whether they would work. MOEE (Ref #1) notes that "...the US Environmental Protection Agency recommends the use of alternate water supplies (including bottled water) when drinking water supplies exceed the standard for tritium."

Because no technologies exist to reduce tritium at water treatment plants, the onus to reduce exposure to tritium, should this be required, would fall either on municipalities to take actions to provide alternative water supplies, or on the current sources of tritium (Ontario Hydro and AECL) to ensure that plant discharges do not reach a level that causes the ODWO to be exceeded at a nearby WTP. The implications of these actions are assessed in sections 7, 8, and 9 below.

3. ODWO OPTIONS UNDER REVIEW

As stated earlier, an ODWO consists of a Maximum Acceptable Concentration (MAC) and an averaging time. Six Combinations of MACs and averaging times are reviewed in this paper (see Table 1).

Since the adverse effects of radiation at low levels result from long term (lifetime) exposure, the Ministry is reviewing the consequences of setting ODWO using averaging times of annual measurement[2]. Concentrations to be examined are 7,000, 100 and 20 Bq/L based on recommendations by the Ministry (Ref #1) and ACES (Ref #3).

Currently, the shortest time period that monitoring is undertaken regularly is weekly. ACES has recommended that the Maximum Acceptable Concentration should be a value, that when exceeded, "an alternate water supply should be made available" (Ref#3, page 28). Consequently, the implications of setting standards on a "not to exceed" weekly basis in addition to a long term (annual) average tritium standard are also considered in this report.

Table 1
ODWO Options Under Review

MAC for Tritium (Bq/L)	Averaging Period
7,000	1. Annual
100	2. Annual
20	3. Annual
7,000	4. Weekly
100	5. Weekly
20	6. Weekly

---

[2] A key variable to be determined in this process is the averaging time assigned to any standard that is recommended. An averaging time is a function of the type of exposure that the Ministry is attempting to protect in setting an ODWO.

1) If the risk of concern is an acute, high lethal type dose, then the action necessary is to prevent and protect against rapid increases in concentration levels so the averaging time should be hourly or weekly.

2) If the risk of concern is a chronic cumulative type dose then the necessary action is prevention and protection from regular cumulative lifetime discharges, and the averaging time can be yearly or longer.

4. CONCENTRATIONS OF TRITIUM AT WATER TREATMENT PLANTS (WTP) NEAR NUCLEAR FACILITIES

4.1 Data From the Nuclear Surveillance Program

There are 19 water treatment plants that are monitored under the Nuclear Surveillance Program. Table A.1 in Appendix A lists the plants. Part of this program involves regular testing of water supplies at water treatment plants in the vicinity of nuclear generating stations in Ontario by the Ministry of Labour.

Table A.1 also lists populations served by the WTPs, the source of raw water supply to the plant and the population served by the WTPs. Approximately 3 million people in Ontario (1/4 of the population) are served by WTPs monitored under this program. Weekly, monthly and annual time series graphs for concentration levels at ten of the seventeen WTPs located near Ontario Hydro facilities are displayed in Appendix B as graphs B1 to B30.

Table A.2 in Appendix A shows the long term average tritium concentration for each of the nineteen WTPs, the maximum concentration recorded during the period, the standard deviation of a moving annual average for the plant and the relation of the weekly maxima tritium concentration to the long term annual average.

From tables A.1 and A.2 in Appendix A and graphs in Appendix B we can conclude that:

- Average concentration of tritium in raw water over the past ten years at WTPs near nuclear facilities range from 5.3 Bq/L (Whitby WTP) to 48.5 Bq/L (Port Elgin WTP). The average over the 19 water treatment plants for which we have data weighted by population served is 11.9 Bq/L.

- The highest annual average recorded is 77.9 Bq/L. This occurred in 1991 at the Port Elgin WTP.

- The annual concentration levels of tritium measured at water treatment plants has been declining over the 10 year period with the exception of 1992 (See Figures **B21-B30**). Levels in 1993 were between 35% and 52% lower than levels in 1983. In 1992 there was a well documented release of tritium at the Pickering Nuclear Generation Station which resulted in an increase in the concentration of tritium in the neighbouring water treatment plants (R.C. Harris WTP, Horgan WTP, Ajax WTP, and Oshawa WTP). The result was a rise in the annual averages above 1991 levels.

- Occasional (about once a year) spikes can result in weekly average concentrations ranging from 1.6 to 31 times the ten year average as indicated in Table A.2.

- The maximum peak level found in weekly samples was 732 Bq/L (Port Elgin).

- On average, over the 19 plants for which we have data, peak spike levels were 9.4 times the average concentration and lasted one to two weeks.

- Tritium concentrations have never exceeded the current ODWO of 40,000 Bq/L limit (annual average or weekly average).

- Concentrations have never exceeded the proposed 7,000 Bq/L standard (annual average, weekly average).

- Concentrations never exceeded 100 Bq/L on an annual average basis.

- Concentrations exceeded 100 Bq/L on a weekly average basis a total of 84 times for the 19 plants in the past ten years as shown in Table 2.

- Concentrations exceeded 20 Bq/L on an annual average basis a total of 29 times at eight different plants

- Concentrations exceeded 20 Bq/L on a weekly average basis a total of over 1,000 times at the 19 plants.

Table 2
Exceedences of Proposed Options

ODWO for tritium (Bq/L)	**Averaging Period**	**Number of Times and Percent Exceeded at Water Treatment Plants[*]**			
		12 WTPs near Ontario Hydro facilities		**4 WTPs near AECL facilities**	
		times	**%**	**times**	**%**
7,000	Annual	0	0	0	0
7,000	Weekly	0	0	0	0[**]
100	Annual	0	0	0	0
100	Weekly	102	2	0	0[**]
20	Annual	29	0.5	4	13.3
20	Weekly	1,119	22	8	3[**]

* Data were complied for a 10 year period for WTPs near Ontario Hydro facilities. At AECL nuclear facilities, data were available within 2 to 4.5 years.

** The averaging period for WTPs near AECL facilities is monthly as opposed to weekly for WTPs near Ontario Hydro facilities.

SOURCE: Ministry of Environment and Energy Calculations

4.2 Tritium Concentrations Associated with The Proposed Pickering/Ajax Water Treatment Plant

MOEE undertook the revision of the tritium in drinking water objective in response to the Minister's acceptance of recommendations made by the Environmental Assessment Advisory Committee (EAAC) regarding a proposed Pickering/Ajax Water Supply Plant and the need for an appropriate standard for tritium.

The intake for the proposed water supply plant is currently under design and will draw water from a depth of 60 feet extended offshore a distance of approximately 8,400 feet. The intake location was selected following an extensive water sampling program which was carried out by the Region of Durham as background information for an Environmental Study Report.

At the request of the Pickering/Ajax Water Supply Plant Committee the Region of Durham initiated a supplementary tritium sampling program in the summer of 1993. Under the supplementary program water quality samples were collected and analyzed for tritium concentrations on a Monthly basis from August 1993 to April 1994 at three locations including (i) the existing Ajax WTP intake, (ii) the proposed intake alignment at sixty foot-depth and (iii) the proposed intake alignment at one hundred and twenty foot depth.

For this sampling program, two samples were taken at each location including a surface water sample and a sample at depth. The results of this sampling program to date are provided in Ref #7. The average concentration and maximum concentration of tritium at the location and depth (sixty feet) of the proposed intake were 7.4 Bq/L and 10.0 Bq/L respectively.

Over the same period, the average concentration and maximum concentration of tritium at the location and depth (sixty feet) of the existing Ajax WTP intake were 12.2 Bq/L and 32.2 Bq/L respectively.

5. DOSE AND RISKS INCURRED FROM PRESENT EXPOSURE

Dose is a measure of the amount of radiation received by a person or thing exposed to a source of radiation.

According to Health Canada (Ref #2), exposure to ionising radiation, whether natural or artificial, can cause two kinds of health effects as a result of changes to the atoms and molecules of body tissues. Effects for which the damage caused is proportional to the dose received are called deterministic effects. A threshold dose has been identified below which deterministic effects do not occur. Under normal conditions, doses received from natural radioactivity and routine exposures such as drinking water, are well below the threshold levels and therefore deterministic effects are not relevant to this exercise.

Effects for which the probability of occurrence, rather than the damage caused, is proportional to dose are known as stochastic effects. It is assumed by the radiological community that no threshold level exists below which stochastic effects do not occur. The main stochastic effect of concern from low level radiation exposure such as drinking water is the induction of cancer following a variable latent period ranging from several years to several decades, although there is a small probability associated with heredity effects. Stochastic effects are the most important consequence of environmental levels of radiation and serve as the basis for current radiological guidelines.

The international scientific community has developed a system of factors in order to convert concentrations of radionuclides in water to dose of radiation and finally to risk of fatal cancer. Using a dose conversion factor of $2.0x10^{-8}$ Bq/mSv (Ref #2) and assuming that consumption of water is 2 litres per day, the estimated lifetime dose of radiation has been calculated from the average tritium concentration in drinking water samples over the periods of observation. From the dose calculation, the estimated risk of developing a fatal cancer for the population exposed has been calculated based upon the International Committee for Radiation Protection risk recommendation of $5x10^{-2}$ per sievert (Ref #1). The risk factor used to estimate fatal cancers is an underestimate of total risk since it does not include the risk of non-fatal cancer and hereditary effects.

Table 3 lists the estimated dose over the past ten years and associated lifetime (70 years) risk of fatal cancer associated with historical concentrations of tritium at WTPs.

Currently the dose and risk incurred from present exposure to tritium in drinking water is well below the dose from the current standard of 40,000 Bq/L and the proposed MOEE standard of 7,000 Bq/L.

Over the period for which data are available, the doses and associated risks of fatal cancer ranged from a low of 0.0056 mSv with an associated risk of fatal cancer of $2.7x10^{-7}$ in Wheatley to a high of 0.0071 mSv and a risk of $2.5x10^{-6}$ in Port Elgin.

Multiplying lifetime risk (calculated using the ten year average concentration) by the assumed populations exposed at each plant reveals that 2.4 additional deaths from cancer out of a static population of about 3 million people is estimated to occur in a 70 year period in Ontario as a result of observed average exposure to tritium in drinking water. To put this estimate in perspective, approximately 25% of that population or 750,000 people will die of cancer over the same period.

Table 3
Estimated Lifetime Dose and Risk Incurred from Exposure to Tritium

Drinking Water Sources	Population	Months of Data (#)	Long-term Average of Weekly Concentrations over Observed Period (Bq/L)	Lifetime Dose (mSv/lifetime period)	Lifetime Risk[1]	# of Lives at Risk Over a Lifetime
Kincardine WTP[2]	2,864	132	14.2	0.0145	7.3E-07	0.002
Port Elgin WTP[2]	5,909	132	48.5	0.0496	2.5E-06	0.015
Bowmanville WTP[2]	13,750	96	10.2	0.0104	5.2E-07	0.007
Newcastle WTP[2]	37,769	96	10.1	0.0103	5.2E-07	0.020
R.C. Harris WTP[2]	712,679	132	13.6	0.0139	6.9E-07	0.492
R.L. Clark WTP[2]	988,654	70	9.6*	0.0098	4.9E-07	0.484
Horgan WTP[2]	631,957	132	14.4	0.0147	7.4E-07	0.468
Ajax WTP[2]	45,046	113	30.9	0.0316	1.6E-06	0.072
Proposed Ajax WTP[2]	45,046	6	9.6	0.0098	4.9E-07	0.022
Oshawa WTP[2]	120,904	132	19.8	0.0202	1.0E-06	0.121
Whitby WTP[2]	49,948	62	12.5*	0.0128	6.4E-07	0.032
Amherstburg WTP[3]	15,951	54	6.1*	0.0062	3.1E-07	0.005
Harrow-Colchester WTP[3]	3,537	52	5.7*	0.0058	2.9E-07	0.001
Wheatley WTP[3]	1,539	54	5.5*	0.0056	2.8E-07	0
Petawawa WTP[4]	4,500	39	10.7*	0.0109	5.5E-07	0.002
Deep River WTP[4]	7,914	54	6.8*	0.0069	3.5E-07	0.003
Pembroke WTP[4]	16,000	52	11.2*	0.0025	1.2E-07	0.009
Rolphton WTP[4]	N/A	51	6.6*	0.0067	3.4E-07	N/A
Lakeview WTP[2]	700,000	21	8.7*	0.0089	4.4E-07	0.308
Lorne Park WTP[2]	700,000	21	8.6*	0.0088	4.4E-07	0.308
Total	3,358,921					2.37

* Denotes Average of Monthly Values, N/A: Not available.

[1] Fatal Cancer Risk per person exposed

Assumptions: 2 litres of water consumed/day, 365 days/year, 70 years/lifetime
Dose conversion factor 2.0 x 10^{-8} mSv/Bq
Risk of fatal cancer/mSv 5x10^{-5}

[2] Water treatment plants near Ontario Hydro facilities.

[3] Water treatment plants near Enrico Fermi 2, Michigan and Davis Besse, Ohio.

[4] Water treatment plants near AECL facilities.

SOURCE: Municipal Financial Information 1991, Ministry of Environment and Energy Calculations

6. GENERIC OPTIONS TO REDUCE EXPOSURE TO TRITIUM IN DRINKING WATER

Three types of generic actions can be taken in order to reduce exposure to tritium in drinking water.

1. Actions by sources to reduce regular releases and hence chronic exposure.
2. Actions by sources to reduce the intensity and frequency of spikes.
3. Actions by municipalities and others to reduce exposure in the event of a spike.

Types 1 and 2 attempt to change the pattern of tritium releases, while type 3 involves actions to prevent people from consuming water in the event of tritium contamination.

These actions are explained below and illustrated in Figures 1 and 2.

Weekly average tritium concentrations found in the raw water for a hypothetical WTP are plotted in Figure 1. The average concentration over the period was 14.2 Bq/L and two relatively large spikes occurred that have been labelled as A and B.

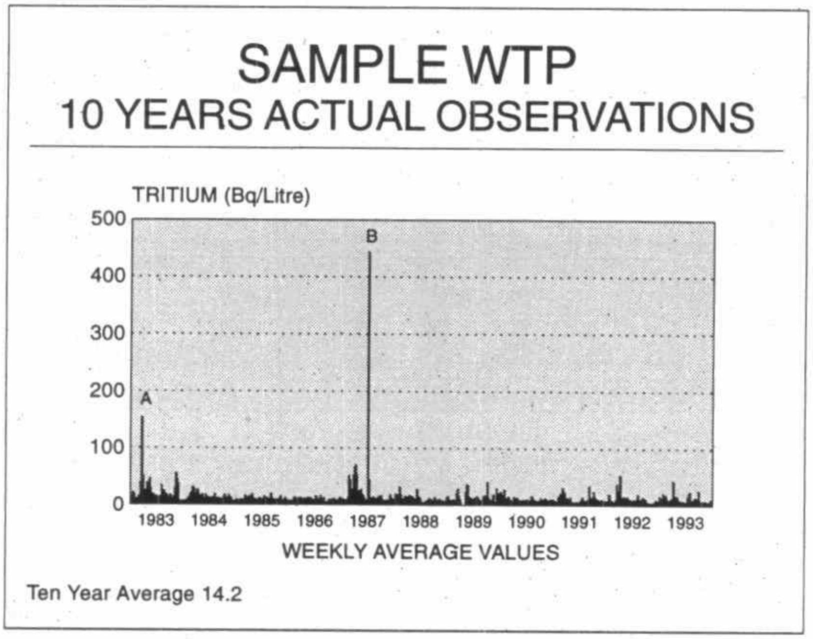
Figure 2 illustrates the hypothetical effect of the first two types of actions:

1) implementing actions to reduce the intensity and frequency of spikes from sources of tritium. Points A and B have been reduced by the actions taken to decrease spikes and consequently the average concentration has decreased marginally to 13.4 Bq/L.

2) implementing actions to reduce regular releases and hence chronic exposure. All regular releases have been reduced to a level below 20 Bq/l and consequently the average concentration has decreased to 12.7 Bq/L, assuming the two spikes remain and to 11.9 Bq/L if we combine the two actions.

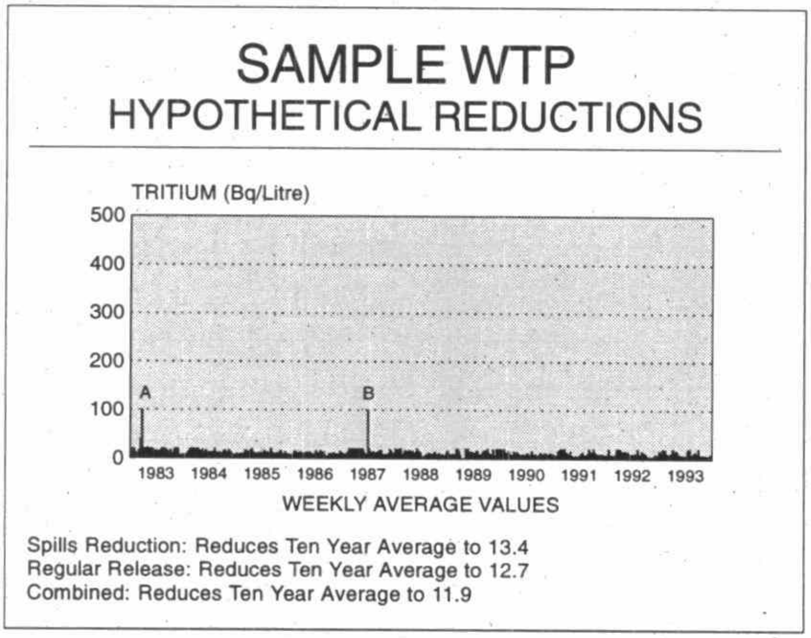
The next two sections of the report describe actions in detail for Ontario Hydro and Atomic Energy Canada Limited. They discuss the current level of litres from each source of tritium, identify the key sources of tritium from the parties affected, potential actions and their estimated costs. Section 9 then describes actions that can be taken to reduce exposure when the MAC is exceeded.

Figure 1


SAMPLE WTP
10 YEARS ACTUAL OBSERVATIONS

Ten Year Average 14.2

Figure 2


SAMPLE WTP
HYPOTHETICAL REDUCTIONS

Spills Reduction: Reduces Ten Year Average to 13.4
Regular Release: Reduces Ten Year Average to 12.7
Combined: Reduces Ten Year Average to 11.9

7. ACTIONS TO REDUCE EMISSIONS FROM ONTARIO HYDRO

The information in this section was obtained from Ontario Hydro and is principally taken from a report submitted to the Ministry on August 26, 1994 titled, A Submission to the Ministry of Environment and Energy on the Potential Impact of Reducing the Ontario Drinking Water Objective for Tritium (Ref #8). Because of the timeframe imposed by the Ministry, the information provided was a preliminary assessment of the actions to reduce tritium to water emissions and not based on detailed engineering studies. As a result, costs and reduction values embody a large degree of uncertainty.

7.1 Ontario Hydro's Current Tritium Limits and Discharges

The MOEE applies ODWO in approving the establishment of any water works or a change in existing water works. Ontario Hydro nuclear plant operation is regulated by the Atomic Energy Control Board (AECB). AECB emission limits for radionuclides are based on international standards set by the International Committee for Radiological Protection recommendations. Maximum annual discharge levels are expressed as DELs (derived emission limits), in terms of the maximum allowable station release of tritium into water and reported in curies (Ci) or becquerels (Bq) per month. The DELs for tritium in water for the five nuclear stations are shown in Table A.4 in terms of TBq/yr[3] and range from 5,300,000 TBq/yr at Darlington to 620,000 TBq/yr at Pickering A and B.

Actual total plant tritium discharges to water over the last 5 years are shown in graphical form in Figure 3 and are much lower than the DEL. The Atomic Energy Control Regulation's require that nuclear facilities establish and implement measures to keep doses received by workers and members of the public As Low As Reasonably Achievable (ALARA), social and economic factors being taken into account (Ref #9). Station operating targets are to emit less than 1% of the current DEL for tritium (on a monthly average basis).

Over this period, the 1% DEL operating target has not been exceeded at any Hydro plant.

The tritium DEL can also be used to calculate a concentration limit for tritium in the station effluent, i.e. the maximum allowable release of tritium in TBq/y divided by the total cooling water flow from the station for the year in litres. This is called the Derived Liquid Concentration (DLC). The annual DLC limits for each station are also shown in Table A.4 and range from 210,000 Bq/L at Pickering (PNGS) to 1.2 million Bq/L at Darlington (DNGS).

Depending on the level of the ODWO for tritium, Ontario Hydro might have to adjust its operating target for each plant in order to ensure with sufficient probability, that concentrations of tritium at nearby WTPs would not exceed the ODWO. The probability and dispersion model calculations have not been made at this time. However, Ontario Hydro possesses dispersion models which can link discharges from their plants to concentration levels at nearby WTP. The models are only effective when estimating annual levels of tritium. Their ability to link short term discharges and weekly sample levels at WTPs is limited.

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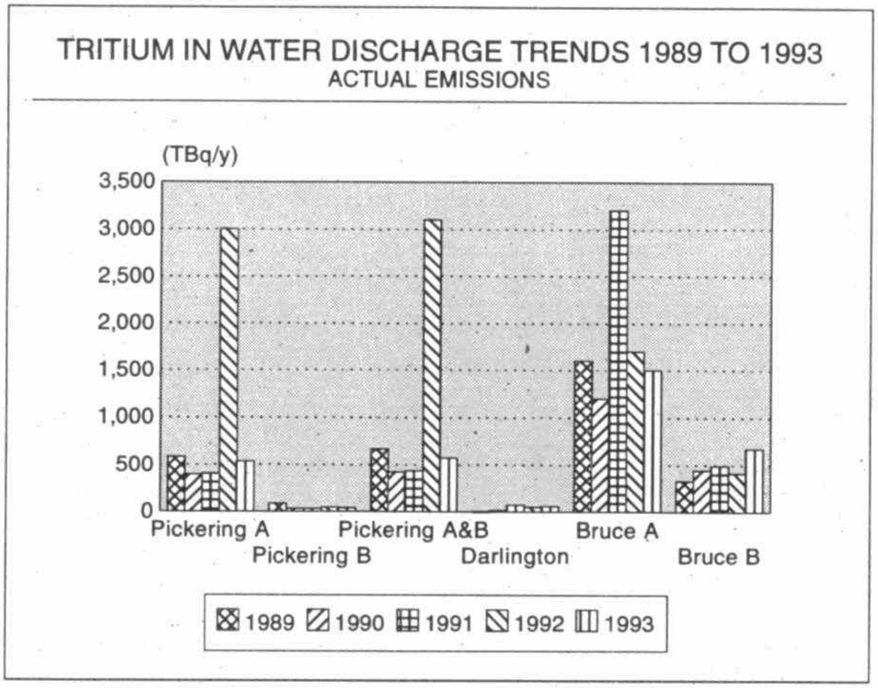
[3] $1 \text{TBq} = 1 \times 10^{12} \text{Bq}$

Figure 3



7.2 Tritium Releases from Ontario Hydro Nuclear Plants

Tritium is an unavoidable by-product of neutron activation of the heavy water systems (D_2O) in a CANDU reactor.

The key sources of tritium can be grouped into two major categories; regular or continuous releases due to minor leakage, maintenance and housekeeping, and spikes due to equipment failure.

7.2.1 Releases - Minor Leakage, Maintenance and Housekeeping

Tritium escapes from the heavy water systems due to minor equipment leakage during normal operation and from maintenance activities.

Leakage from Upgraders

The station design includes a heavy water recovery system where anticipated leakage with expected higher D_2O concentrations is collected, purified, upgraded and reused. This water contains tritium. There are relatively small D_2O/tritium losses from the upgraders (about 10% of all releases at the Pickering plant in 1993).

General Leakage

The remaining sources of leaks come from the active drainage system to the Active Liquid Waste (ALW) system. This system also collects contaminated water from housekeeping activities such as laundry and tool decontamination. Not all sources are monitored individually because the tritium levels are extremely low and the benefits of identifying the sources are not believed by Ontario Hydro to warrant incurring the monitoring costs. Waste water collected in the ALW system tanks is sampled and analyzed, treated if necessary and then pumped out to the lake via the Condenser Cooling Water (CCW) discharge. However, the ALW system treatment methods (decay tanks, filtration and ion exchange) cannot remove tritium.

7.2.2 Spikes due to Equipment Failure

Larger amounts of tritium than regular releases may escape in the event of internal equipment failure, releasing D_2O and tritium to light water systems (e.g. lake cooling water) and eventually being discharged into the receiving water.

Heat exchanger tube leak or rupture

Heat exchangers, such as the moderator heat exchanger are cooled directly by lake water (service water). Tritium discharges have occurred as a result of a heat exchanger (HX) tube leak or rupture. Service water is monitored for radioactivity regularly. However, some tritium escapes from stations before the faulty equipment is shut down and isolated. Pickering Nuclear Generating Station has very recently improved its leak detection capability by installing online tritium monitors in their reactor building service water (RBSW) effluent stream.

Leaks of tritium due to cracks in boilers

Another key source of tritium spikes is equipment failure in the boilers. Although not cooled directly by lake water, a tube leak (of heat transport D_2O) in a boiler can contaminate the secondary light water side. Boiler blowdown is drained to the CWW discharge providing a pathway for tritium from boiler tube leaks to the lake. Boiler problems have contributed to leaks over the last several years.

Some tritium discharges have also been caused by leaks from other heat exchangers containing D_2O, but the moderator heat exchangers and the boilers have been the major sources in the heat exchanger category.

Ontario Hydro's estimated breakdown of the distribution of tritium releases between regular releases and spikes is contained in Table 4. A more detailed breakdown can be found in Table A.3 in Appendix A. Lower percentages of tritium are released from equipment failure at Bruce B and Darlington and are reflected in lower total discharges at these plants.

Table 4
Distribution of Tritium Releases
between Regular Releases and Spikes

Nuclear Facility	% of Tritium from Regular Releases (Leakage)	% of Tritium from Spikes (Equipment Failure)
PNGS	40-70	30-60
BNGS-A	29-70	30-71
BNGS-B	80	20
DNGS	100	0

SOURCE: Ref #10

7.3 Description and Costs of Current Actions to Reduce Tritium

In response to the ministry's (MOEE) request for cost information on existing measures and programs to reduce tritium emissions, Ontario Hydro identified several programs within their facilities which are intended to reduce future tritium discharges.

The work described below is being performed for many reasons, including improving steam generator reliability and safety, not just to reduce tritium discharges to the environment. However, the end result of all these programs will be to reduce tritium discharges.

Programs now in place for minimizing leakage/failures in the boilers and major heat exchangers include:

1) Improved chemical control, inspections, water lancing, tube plugging and electrosleeving in the boilers.

2) Inspection, repairs and/or replacement of aging moderator heat exchangers.

Total cost of these ongoing programs at all Ontario Hydro facilities to the end of 1998 including replacement energy costs has been estimated by Ontario Hydro to be **about $1 billion** (Ref #11). More detail about the programs and the calculation of costs can be found in Appendix C.

Both of these programs should reduce the frequency of occasional spikes like the one that occurred in August of 1992.

3) The existing tritium management program consists of collecting heavy water and sending it from all Ontario Hydro nuclear stations to the Tritium Removal Facility (TRF) located on the Darlington NGS site. Heavy water is collected in a number of systems including:

   a) The heavy water cleanup system which collects leakage and spills of D_2O from the moderator and heat transport systems;

   b) The vapour recovery system which uses dryers to trap any D_2O found in the atmosphere of the reactor vaults and other areas where high concentrations of D_2O may occur before it can be discharged to the environment via the ventilation exhaust; and

   c) The upgrader plant which removes any unwanted light water found in the D_2O which was collected from leakage and upgrades D_20 to its original high isotope concentration for reuse in the reactors.

At the TRF, the D_2O is treated to remove much of the tritium and then returned to the station of origin. This program reduces the impact of both the regular discharges from a large number of small sources and the occasional discharge from equipment failures.

A summary of the capital and operating costs for the above systems is found in Table C.1 in Appendix C. The total equipment cost is about $600 million and the operating/maintenance costs are about $97 $million/yr.

7.4 Potential Technologies and Future Actions that can Reduce Releases of Tritium

Ontario Hydro has submitted six broad actions/options for further reducing tritium releases, covering actions that would reduce regular releases and actions that would reduce spikes due to equipment failure. The actions are summarized in Table 5. Costs listed in the table for these actions are total costs for all Ontario Hydro facilities. A brief description of each option is provided below with more detail, where available, contained in Appendix C.

The actions/options described would be applied to the ALW system, the boilers and moderator heat exchangers which have been identified by Ontario Hydro as the key sources of tritium emissions.

7.4.1 Regular Releases from the Active Liquid Waste Management System

The ALW system hold-up tanks contain a collection of waste light water contaminated with small amounts of radioactivity. This waste water comes from a large number of small sources.

Option 1: Pollution Prevention Studies of the ALW system

Ontario Hydro could undertake a study and monitoring program to characterize each of the sources and pathways that feeds the ALW system, in the hope that some sources may be identified as the major contributors. It may then be possible to reduce tritium losses from those sources. The cost of the study is estimated by Ontario Hydro at **$500,000**. Potential reductions in tritium to be achieved will not be known until the study is completed. However, Ontario Hydro's expectations are that the achievable reductions may be small since following the ALARA (as low as reasonably achievable) principle, discharge source reduction has always been a part of normal operations.

Option 2: Detritiation of Waste Water

Another option is to remove the low concentration of tritium from all the collected waste water in the ALW system before it is released to the lake. However, the TRF cannot technically treat large volumes of water with such low tritium concentrations. The only technically feasible method of removing this tritium is by vacuum distillation. Tritium in the ALW would be reduced by a factor of about 1000 to 1. This process is a proven technology and is used at Ontario Hydro for upgrading heavy water that is contaminated with ordinary water.

Based on the costs of existing Ontario Hydro equipment, the capital cost of such a distillation process to handle the ALW of all Ontario Hydro nuclear stations was estimated by Ontario Hydro to be well **over $500 million**. In addition, operating costs are expected to be many millions of dollars per year because of the high energy usage required by this system. The total cost of building and operating such detritiation units for all nuclear stations **could exceed a billion dollars**.

7.4.2 Spike Releases from Equipment Failure

Option 3: Improve Leak Detection

Improved detection of leaks of tritium in water that would escape throughout the plant would allow the faulty equipment to be located and isolated quicker, thus reducing the amount of tritium released. At present, Pickering Nuclear Generating Station is reviewing their tritium leak detection and response capability for all nuclear process systems discharging to the lake. A new type of continuous on-line tritium monitor is being tested at Pickering Nuclear Generating Station to improve the detection and monitoring of tritium in water. Estimate of the costs of the study and the new tritium monitors is **not available at this time** but will be known when the study at PNGS is complete.

Option 4: Recirculating Boiler Blowdown Recovery Water

Tritium which leaks to the light water side of the boilers is released to the lake via boiler blowdown. The boiler blowdown system could be modified so that it is a closed loop or recirculating system, thus eliminating direct tritium releases to the lake. However, concentration of tritium and other chemicals would build up in the boiler/feedwater/steam system. This would likely **increase discharges of tritium to air** and therefore would have to be combined with a new vacuum distillation process described above to remove the tritium. The capital cost of modifying the boiler blowdown systems of all nuclear plants has been estimated at about **$150 million** plus **$500 million** for vacuum distillation.

Option 5: Closed Loop Cooling for Heat Exchangers

Providing another layer of containment for heat exchangers could also reduce tritium. Ontario Hydro could modify all heat exchangers that are now cooled directly by lake water so that they recirculate cooling water in the nuclear systems. These closed loop systems could then, in turn, be cooled by lake water through additional heat exchangers.

This would be a major structural change to Ontario Hydro's facilities and feasibility is not known. The cost of modifying all heat exchangers cooled directly by lake water and adding another cooling system for each was described by Ontario Hydro staff as, "*prohibitively costly if it were even feasible, given the physical constraints of existing plant.* (Ref #8)" Furthermore, this action would require chemicals to condition the closed loop cooling water which could themselves constitute potential pollution problems.

Option 6: Replace Aging Boilers and Heat Exchangers Sooner Than Currently Planned

A fifth option to minimize occasional unexpected equipment failures (and thus tritium releases) would be to replace aging equipment much sooner than currently planned. According to Ontario Hydro staff "*Considering the cost of major heat exchangers and boilers (hundreds of millions to billions of dollars), this would be a prohibitively costly measure.*(Ref #8)."

Table 5
Technologies and Costs of Reducing Tritium at Ontario Hydro Nuclear Facilities

Technology	**Cost**	**Effects on Tritium Releases**
	Regular Releases	
1. Pollution Prevention Studies	$500,000	Depends on findings of study
2. Detritiation of Active Liquid Waste Water by Vacuum Distillation	<$500 million - capital many millions - operating	1,000 fold in ALW discharges which range from 29% - 100% of plant discharges
	Spikes	
3. Improve Leak Detection*	Currently being studied	Avoid spikes such as August 1992 release
4. Boiler Blowdown Recovery*	$150 million - capital	Reduce water emissions at expense of increased air emissions made
5. Closed Loop Cooling for Moderator Heat Exchangers*	"not estimated but prohibitively costly"	Feasibility not known
6. Boiler Replacement Moderator Heat Exchange Replacement*	"hundreds of millions to billions"	No estimate made

* These technologies will reduce the probability of a spike occurring. Therefore reduction efficiency not known.
SOURCE: Ontario Hydro Submission Ref #8.

Ontario Hydro has summarized the conclusions of their study in relation to the alternative drinking water objectives under review in this paper (Ref #10). Ontario Hydro has also noted implications for the release of other radionuclides which are explained in section 11.

7.5 Conclusions

- If the ODWO is set as an annual average of 7,000 Bq/L then no actions are required by Ontario Hydro.
- If the ODWO is set as a weekly average of 7,000 Bq/L then no actions are required by Ontario Hydro.
- If the ODWO is set as an annual average of 100 Bq/L then no actions are required by Ontario Hydro for tritium in water other than to ensure that releases remain at or below the levels found historically[4].

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[4] Costs related to removal of other radionuclides of about $400 million are described in Sections XI.

Table 6
Evaluation of Technical Options

ODWO Option	Action Required to Meet ODWO	Cost to Comply with ODWO
7,000 Bq/L annual/weekly average	No further action required	$0
100 Bq/L annual average	No further action required	$0
100 Bq/L weekly average	Actions to reduce spikes	$650 million to billions of dollars
20 Bq/L annual average	Actions to reduce spikes at all Ontario Hydro facilities. Actions to reduce regular releases at Bruce and Pickering.	$500 million to billions
20 Bq/L weekly average	Actions to reduce spikes combined with actions to reduce regular releases	Billions of dollars

SOURCE: Ref #10

- If the ODWO is set as a weekly average of 100 Bq/L then actions are required by Ontario Hydro to reduce spikes at an estimated cost of between $650 million and over $1 billion.

- If the ODWO is set as an annual average of 20 Bq/L then major actions are required to reduce spikes at all Ontario Hydro plants and to reduce regular releases at the Bruce Nuclear plant. Costs ranging from $500 million to billions would have to be incurred by Ontario Hydro to meet the level.

- If the ODWO is set as a weekly average of 20 Bq/L then actions are required to reduce spikes and regular releases at all Ontario Hydro facilities at a total cost of billions of dollars.

8. ACTIONS TO REDUCE EMISSIONS FROM ATOMIC ENERGY CANADA LIMITED (AECL)

The information in this section was obtained from Atomic Energy Canada Limited and is principally taken from a report submitted to the Ministry on September 28, 1994 titled, Atomic Energy of Canada Limited Submission to the MOEE on the Potential Impact of Reducing the Ontario Drinking Water Objective for Tritium (Ref #17). Because of the timeframe imposed by the Ministry, the information provided was a preliminary assessment of the actions to reduce tritium to water emissions and not based on detailed engineering studies. As with the Ontario Hydro analyses, costs and reduction values embody a large degree of uncertainty.

8.1 AECL's Current Tritium Limits and Discharges

AECL operates two nuclear facilities in Ontario, the Chalk River Laboratories (CRL) and the Nuclear Power Demonstration (NPD) plant. Both of these facilities are regulated by the Atomic Energy Control Board (AECB).

The NPD plant and CRL are both located on the shores of the Ottawa River in Ontario's Renfrew County. The NPD plant is a partially decommissioned 75 MW (electrical power) CANDU prototype nuclear generating station that last operated in 1986. The CRL site is located approximately 20 km downstream from the NPD and has a number of nuclear facilities. The CRL facilities are used for basic and applied research in atomic energy and related technologies (including R&D in support of current and future CANDU reactors) , the production of radioisotopes for medical diagnoses and treatment, and radioactive waste management. The largest facility is the 135 MW (thermal power) NRU research reactor.

The AECB approved emission limits for radionuclides from these facilities, known as Derived Release Limits (DRLs), are based on the regulatory limits for radiation dose to members of the public, considering not only drinking water but all significant environmental pathways leading to exposure.

The DRLs for tritium in water for the two nuclear stations are shown in Table A.4.1 in terms of TBq/yr[5]. In 1993 the limits ranged from 10,800 TBq/yr at NPD nuclear station to 36,000 at CRL nuclear station.

Actual total plant tritium discharges to water over the last 5 years are shown in graphical form in Figure 4 and are much lower than the DEL. as noted earlier, Atomic Energy Control Board Regulation's require that nuclear facilities establish and implement measures to keep doses received by workers and members of the public As Low As Reasonably Achievable (ALARA), social and economic factors being taken into account (Ref #9).

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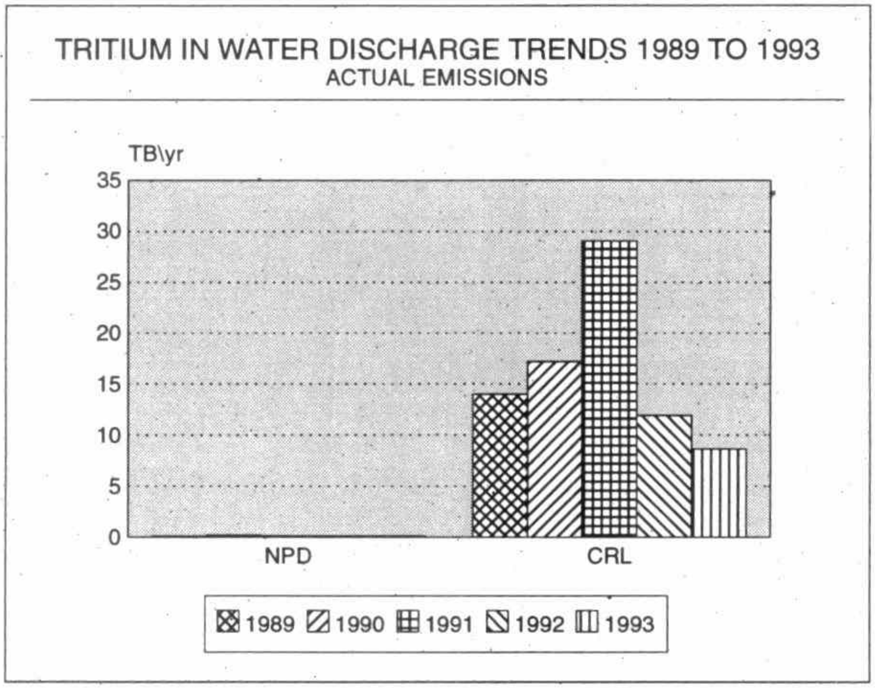
[5] $1TBq = 1x10^{12}Bq$

Figure 4



8.2 Key Sources of Tritium from AECL's Nuclear Plant

Tritium releases occur as a result of minor leakage and spillage during normal operation and maintenance. Occasionally somewhat larger releases occur as a result of equipment failures such as failures of heat exchangers, or piping failures. Where practical, leakage or spillage is collected and recovered. The material which cannot be recovered is discharged directly or indirectly in various waste streams. In the case of heat exchanger leaks or failures, losses may occur by way of the secondary cooling water effluent.

As noted in 8.1 above, the NPD reactor has been shutdown since 1986 and is partially decommissioned. It no longer represents a significant source.

Leakage from NRU research reactor

At CRL the main source of past and present tritium discharges is the NRU research reactor, which is cooled and moderated with heavy water. Minor leakage and/or spillage may occur from pump seals, valves, and other heavy water system components system during normal operation and maintenance. Small unavoidable losses may also occur during fuelling operations with the fuelling machine, particularly during almost daily removal of targets for production of medical radioisotopes.

The peak release from CRL during 1988 (Figure 4) was the result of failure of a heavy water pump in NRU. Although most of the spilled heavy water was collected and recovered for upgrading, a fraction was released directly as a result of a previously unrecognized release route, and some indirectly as wastewater that was downgraded below the practical limits for recovery and upgrading.

Leakage from the NRX research reactor

A second significant source of past tritium emissions from CRL was the NRX research reactor, which was heavy water moderated but employed light (natural) water for fuel cooling. NRX has been shutdown since 1992 and is to be decommissioned; **it is no longer a significant source.**

Equipment Failure and leaks in the Heavy Water Upgrading Plant.

A third significant source at CRL is the Heavy Water Upgrading Plant. This facility employs an electrolysis process to restore recovered and downgraded heavy water to reactor grade for reuse. Minor discharges occur as a result of minor leakage and spillage, and as residual tritium in waste light water after completion of the upgrading process to the practical limits of recovery. A heat exchanger failure in the Heavy Water Upgrading Plant resulted in the larger than normal release in 1991.

Other Sources

Other sources of CRL tritium emissions include: some in-ground waste management facilities which receive (or received in the past) tritiated waste from other CRL facilities (since tritium is essentially water, it will move with the groundwater); and the tritium research laboratories which carry out research and development on tritium technologies and safety in support of CANDU reactors and nuclear fusion research.

8.3 Potential Technologies and Future Actions that can Reduce Releases of Tritium

The facilities at CRL have been designed to minimize the release of tritium within the practical constraints of the technology available at the time of their construction. One of the motives for this minimization of tritium releases is the need to minimize the associated loss of heavy water which costs about $400/kg.

Option 1: Retaining Releases of Tritium

The tritium concentrations at the downstream water supply plant intakes could be maintained below the 100 Bq/L recommended by ACES by installing equipment to reliably retain tritiated heavy water that is released due to equipment faults or other process upsets. This retained water would then be later released in a controlled manner so as not to exceed the 100 Bq/L limit. The two facilities at CRL that contain significant quantities of tritiated heavy water in process equipment are the NRU research reactor and the heavy water upgrader. The following equipment (see Table 7) would be required to retain tritiated heavy water released during process upsets in these facilities.

It should be noted that the equipment would not reduce the tritium released to the river. It would only stretch out the duration of the releases so as to prevent peak concentrations at downstream water supply plants from exceeding 100 Bq/L. The reason for releasing the retained water to the river is that it is very difficult to recover heavy water or tritium that is highly diluted in ordinary water. This is explained further in the following paragraphs.

Table 7
Costs of Reducing Tritium Concentrations to a 100 Bq/L Weekly Average

	Description Of Equipment	Estimated Cost
1.	Dedicated radioactive drain system for heavy water processes (drain system to have large catch tanks to retain and temporarily store released heavy water).	$10,000,000
2.	Continuous tritium monitoring and leak detection on all individual sources of tritium.	$3,000,000
3.	Secondary heat transfer loop on all heavy water heat exchangers.	$50,000,000
4.	Heavy water process equipment redundancy.	$20,000,000
5.	Increased maintenance costs due to the need to replace heavy water process equipment as soon as minor leaks develop.	$1,000,000/year
	Total - process upset and recovery costs	~$80,000,000 initially plus $1,000,000/year thereafter

SOURCE: AECL Submission Ref #17.

Vacuum Distillation

Tritium cannot be removed from water by using technologies that are used for removing chemical contaminants. Tritiated water has the same chemical properties as ordinary water and it can only be separated from ordinary water using isotope separation technologies. These technologies are generally much more expensive than chemical contaminant removal technologies. Most of the isotope separation technologies that are available cannot process relatively large volumes of water and achieve the very low tritium concentrations needed in the treated output. Vacuum distillation is the only feasible method identified for meeting this requirement. The estimated volume of recovered tritium contaminated water is 15,000 m^3/a. Two 1,000 kg/hr vacuum distillation units would be required to process this water. The estimated cost of the vacuum distillation plant is $67,000,000.

IRUS disposal

A reduction of tritium releases from the waste management areas can be achieved by diverting all waste having significant tritium content from the sand trench facility to concrete bunkers and subsequent disposal in an Intrusion Resistance Underground Structure (IRUS) facility. The costs of diverting 1,000 m^3/year of tritium contaminated waste from sand trench to concrete bunker and IRUS are estimated to be $6,000,000 per year.

Table 8
Costs of Reducing Tritium Concentrations to 20 Bq/L Weekly Average

Description of Equipment		Estimated Cost
1.	Process Upset Recovery Equipment (see previous table for details)	~$80,000,000 plus $1,000,000/year
2.	Vacuum distillation plant (2,000 kg/hr capacity)	$67,000,000
3.	Diversion of all tritium contaminated waste to concrete bunker and IRUS disposal.	$6,000,000/year
TOTAL - TRITIUM RECOVER, EXTRACTION AND STORAGE COSTS		~$150,000,000 initially plus $7,000,000/year thereafter

SOURCE: AECL Submission Ref #17.

Most of the costs associated with the release control strategies described above are brought about by the ACES requirement to control tritium on a not to exceed peak concentration basis. This departs from international practice of controlling long-term radiation exposures on a time average basis. If one were to apply the ACES recommended immediate reduction to 100 Bq/L on an annual average basis, the limit could be currently met at water supply plants downstream of both NPD and CRL[6]. The 20 Bq/L limit applied on an annual average basis could be currently met at Deep River (downstream of NPD) and could probably be met downstream of CRL with some additional, recovery control and intervention measures at CRL. Although specific measures have not been identified, the cost is probably equal or less than the $80,000,000 for recovery and control measures estimated for compliance with 100 Bq/L peak not to exceed the limit.

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[6] Costs related to the removal of other radionuclides are described in section XI.

9. ACTIONS TO REDUCE EXPOSURE ONCE AN EXCEEDENCE HAS OCCURRED.

As described in Section 2, the principal implications of a much lower ODWO for tritium would fall on the sources of tritium to reduce the quantity of their discharges and the probability of spikes. However, in view of the fact that releases could still occur and cause the Maximum Acceptable Concentration (MAC) level to be exceeded, and that costs of control actions may be costly, one of the possible options to comply with a lower ODWO may be to require actions to reduce exposure in the event that the MAC is exceeded.

This is particularly the case if the ODWO were applied to weekly average samples.

Currently when a raw water sample of tritium is greater than the MAC the following sequence of actions and events is initiated.

1. Start more frequent (daily, hourly) testing at WTP

2. Use monitoring values (Bq\L) to calculate

    i) average concentration (Bq\L) to compare to MOEE ODWO(Bq\L) and
    ii) dose (rem) as per Emergency Planning Ontario to compare to protective action levels (PAL).

3.
    - If monitoring value (Bq/L) > MOEE MAC or is increasing, continue monitoring

    - if average concentration (Bq/L) > MOEE ODWO, warn water drinkers not to drink the water, and to seek alternative drinking water supplies.

    - if dose value > PALs then Emergency Planning Ontario takes over

    - When monitoring value (Bq/L) < MOEE MAC and is decreasing, and average concentration (Bq/L) < MOEE ODWO, return to pre-elevated level activity.

A more detailed description of the stakeholders involved and their response is contained in Appendix D.

9.1 Description of Actions and Costs to Reduce Exposure

This section describes the costs to municipal water utilities, water consumers and to the Provincial Government that may be incurred to reduce exposure once the MAC has been exceeded. It describes the current cost of monitoring and the potential cost of providing alternative water supplies.

9.2 Cost of Sampling

Currently the cost of analyzing water samples for tritium at a detection limit of 20 Bq/L is $15.00 per sample and at a detection level of 7 bq/L the cost would increase to $34.00 per sample (Ref #12). During the August 1992 spike, samples of raw and finished water were taken at approximately two-hour intervals (Ref #13) . A total of 668 samples of tritium were analyzed over two weeks for a total estimated cost of $10,020.

9.3 Cost of Alternate Water Supply

Once notified that an exceedence has occurred, the water treatment plant operators have a number of options to reduce exposure:

- stop pumping water immediately and/or
- provide an alternative drinking water source
    i. from within the distribution system from other plants, intakes and reservoirs.
    ii. bottled water

Stop pumping water immediately

Temporarily shutting down water treatment plants makes fire protection infeasible. Fire protection must be maintained which is only possible if water pressure is upheld through plant operation. It should also be noted that temporarily shutting down water treatment plants cause sanitary problems due to lack of water for flushing toilets, bathing, washing dishes and clothes, etc. Elevated tritium levels may continue for two or more weeks and the lack of sanitary facilities and fires may cause a much greater loss of life than the tritium exposure would. Furthermore a pumping shut down allows contaminated water to seep into the supply system and contaminate the water at the water treatment plant. Back pressure can cause pipes to collapse and the chlorine residual cannot be maintained in the system so that water left in the system must be flushed out before pumping resumes (Ref #14).

This is an option taken only in dire circumstances

Providing an alternative drinking water source

An alternative drinking water source can come from:

i. within the distribution system from wells, other treatment plants, intakes and/or reservoirs.

Very few plants have the ability to draw raw water from multiple sources, given the contamination of one supply. Some smaller plants can draw from wells in emergencies but this option is not available for many of the water treatment plants listed in Table A.1 (Ref #14).

Treatment plants have varying amounts of storage capacity for emergency use. Smaller plants can have a full day of reserve, while larger plants may have only several hours. However, ESB was unable to catalog the reservoir capacity of the 19 WTP of concern.

For this option to be feasible, municipalities would have to build sufficient storage capacity to supply drinking water for the duration of an exceedence of the ODWO. Alternatively, municipalities could invest in linking their WTP to other WTPs through the intake distribution system. Both of these types of actions are large cost infrastructure changes that could cost millions of dollars.

ii. bottled water

As a rule, people consume two litres of water a day. At an estimated price of $0.50 per litre per person (OCWA), the expenditure would be $1 per person per day.

Using the populations served listed in Table A.1 and assuming the exceedence lasted 14 days, the cost of alternative supplies could range from $40,000 to over $9 million (Table A.5) per incident at a given municipality depending on the water treatment plant affected.

10. RISKS AND RISK REDUCTION - BENEFITS OF AN ODWO for TRITIUM OF 7,000, 100 AND 20 Bq/L.

The primary benefit from a reduction in tritium levels in drinking water will be a reduction in the risk of health effects as a result of exposure to tritium.

Past data was used to simulate the revised dose associated with a revised ODWO for tritium set on a weekly average basis, and hence the risk of stochastic effects. All observed weekly values that exceeded the proposed ODWO option were reduced to 80% of the objective (i.e. 80 Bq/L if ODWO option was 100 Bq/L) to simulate a hypothetical distribution of tritium concentrations. A value lower than the ODWO was chosen as a target because sources of tritium would have to ensure that discharge levels are sufficiently low to meet the standard with some comfort level. Eighty percent was chosen arbitrarily by ESB staff. This methodology may understate the risk reduction to the extent that actions taken by sources to ensure levels are below the ODWO at one WTP close to a nuclear facility may also lower concentrations at other WTPs well below the Maximum Acceptable Concentration (MAC).

Table A.7 lists the current long term average tritium concentration for each water treatment plant along with a revised average incorporating the assumptions listed above.

If the ODWO was set at 100 Bq/L on a weekly basis, the reduction in concentration ranges from 0 to 12 Bq/L in long term average concentration over the 19 plants studied. This translates into a reduction in lifetime risk ranging from 0 to 6.2×10^{-7} over the 19 plants or a maximum total of 0.04 lives saved over 70 years.

Assuming the ODWO was set at 20 Bq/L on a weekly basis, the reduction in concentration ranges from 0 Bq/L to 33 Bq/L in long term average concentration. This translates into a reduction in lifetime risk of between 0 and 1.7×10^{-6} or a maximum of 0.29 lives saved over 70 years.

Again, to put these estimates into perspective, approximately 25% of the population who obtain their drinking water from the WTPs identified in this analysis or 750,000 people will die of cancer over the same period.

11. IMPLICATIONS FOR OTHER RADIONUCLIDES

The report by ACES recommends setting an ODWO for tritium without accounting for exposure from other radionuclides. Exposure to tritium in water is one of the lowest dose impacts from Ontario Hydro and AECL nuclear plants. For example, At the Pickering Nuclear Generating Station, tritium in water emissions accounted for less than 1% of exposure to radiation in 1993. Tritium in air, carbon 14 and noble gases constituted the majority of exposure to radiation from the PNGS (Ref #15).

ACES has proposed that the existing method of regulating toxic chemicals be adopted for regulating radionuclides. They have suggested that standards for each radionuclide be determined in each medium based on a very low de minimis risk level of between 1 and 5 in a million for lifetime (70 year) exposure. If the Ministry adopts the ACES recommendations, then the method and risk basis might have to be applied to other radionuclides in order to maintain a consistent approach for protecting the public health.

As noted earlier, the Ministry of Labour's, Radiation Protection Service Laboratory, currently monitors weekly and monthly composite samples of tritium as part of the Ministry of Environment and Energy's radiological survey. Other radionuclides monitored in conjunction with tritium are cesium-134, cesium-137, iodine-131, cobalt-60. For the period 1989 - 1994, levels of these 4 other radionuclides have always been below the detection limit of 0.3 Bq/L. In addition, gross alpha and beta determinations were routinely performed on all sampled water treatment plants except for Lakeview and Lorne Park. Gross alpha and beta testing are not capable of detecting low levels of tritium. However, the determinations do give a general indication of other possible radionuclides present in water. For the period 1989 - 1994, average gross beta levels have ranged from 0.05 - 0.17 Bq/L with maximums ranging from 0.08 - 1.1 Bq/L. Gross alpha levels averaged 0.03 Bq/L with maximums ranging from 0.04 - 0.40 Bq/L.

The application of radionuclide Maximum Acceptable Concentrations (MACs) is only valid when there is only one radionuclide present in water. Otherwise, a restriction for multiple radionuclides must be met which takes into account contribution from other radionuclides (Ref #5). Current monitoring results suggest the contribution from other radionuclides in drinking water is small.

Ontario Hydro and ACEL currently meet AECB release limits for all radionuclides (Ref #16). However, if the method proposed by ACES is applied to other radionuclides, both agencies estimate that substantial reductions would be required of each affected radionuclide to meet the ACES equivalent risk level. Ontario Hydro estimates that it would have to reduce release of other radionuclides by factors ranging from 1.2 times current emission levels for tritium in air at the BNGS to meet the 5 in a million risk, to 34 times current levels for noble gas in air at PNGS to meet the 1 in a million risk (Table A.6.1). AECL estimates that it would have to reduce the release of other radionuclides by factors ranging from 280 for Noble gases to 1.6 for Stronium-90 in liquid discharges.

Furthermore, the ACES' proposal applies to tritium in drinking water from natural (which are small) and man-made sources. For radionuclides where exposures result from a mix of natural and man-made sources it may not be possible to reach levels consistent with the ACES' methodology (i.e. because natural environmental levels are already higher than levels consistent with ACES' methodology [e.g. Carbon 14]).

Thus while adopting a level of 100 Bq/L averaged annually for tritium in drinking water would not have an immediate impact on Ontario Hydro and AECL with regard to tritium in drinking water, the application of the methodology to other radionuclides could have a very large financial impact. Ontario Hydro estimates the cost at approximately $390 million in capital costs and $3 million per year in operating costs (Ref #11). AECL estimates the costs in the billions of dollars order of magnitude (Ref. #17).

12. CONCLUSIONS

Six options for an ODWO for tritium are reviewed in this paper. Levels to be examined are 7,000, 100 and 20 Bq/L based on recommendations by the Ministry and ACES each with weekly or annual averaging times.

☞ Current levels of tritium in drinking water are significantly below 7,000 Bq/L.

☞ The operating practices at nuclear facilities licensed by AECB have led to tritium emissions low enough that average levels over the 19 plants for which we have data were 11.9 Bq/L.

☞ Over the ten year period for which data is available, the estimated lifetime dose and associated risk of fatal cancer was very low ranging from 0.0056 mSv (risk of $2.7x10^{-7}$) to 0.0122 mSv (risk of $2.5x10^{-6}$) across 19 WTPs.

☞ Multiplying current lifetime risk (calculated using the observed ten year average concentration) by populations exposed reveals that the weighted average lifetime dose is 0.0122 and under this exposure 2.4 additional deaths from cancer could occur as a result of exposure to tritium over a 70 year period.

☞ Exposure to tritium has decreased over time and actions are underway at Ontario Hydro and AECL to reduce both average levels and events such as the August 1992 spill.

☞ No technologies exist to reduce tritium at water treatment plants so the impact of lower ODWO are twofold: increased onus to reduce tritium from sources and increased probability that provision of alternative water supplies of drinking water may be necessary.

☞ Assuming an exceedence of the ODWO lasted 14 days, the cost of alternative water supplies could range from $40,000 to over $9 million (Table A.5) per incident depending on the water treatment plant affected. The costs could be much greater if the water treatment plants are shut down, as noted on page 29. Consequently, social costs from increased public concern would be additional.

☞ If the ODWO is set as an annual or weekly average of 7,000 Bq/L then no actions are required, the dose and risk levels would remain the same and no costs would have to be incurred by sources of tritium.

☞ If the ODWO is set as an annual average of 100 Bq/L then no actions are required for Ontario Hydro, AECL or municipalities for tritium in drinking water. The dose and risk levels would remain the same and no costs would have to be incurred. There could be increased public concern as the Maximum Acceptable Concentration ODWO level would be exceeded at individual times in any given year.

☞ However, if the ODWO is set as an annual average of 100 Bq/L, a precedent will be set for future decisions in Ontario and elsewhere concerning acceptable public exposures to radioactive material. This may have a very large economic impact on Ontario Hydro and AECL, and other sources of ionizing radiation.

☞ If the ODWO is set as a weekly average of 100 Bq/L then actions would be required by Ontario Hydro to reduce spikes in discharges, at an estimated cost of between $650 million and over $1 billion. AECL has estimated the cost of complying with a weekly average of 100 Bq/L at $80 million capital cost and $1 million/yr operating costs.

The dose level would fall to a weighted average of 0.0120 mSv resulting in the saving of 0.04 lives over the population exposed over a 70 year period.

☞ If the ODWO is set as an annual average of 20 Bq/L then actions would be required to reduce spikes at all Ontario Hydro plants and to reduce regular releases at the Bruce and Pickering Nuclear plant. Costs ranging from $500 million to billions would have to be incurred by Ontario Hydro to meet the level. AECL estimated the cost of meeting this requirement at less than $80 million. The dose and risk levels would not change significantly.

☞ If the ODWO is set as an annual average of 20 Bq/L, a precedent will also be set for future decisions in Ontario and elsewhere concerning acceptable public exposures to radioactive material. This may have a very large economic impact.

☞ If the ODWO is set as a weekly average of 20 Bq/L then actions would be required to reduce spikes and regular releases at all Ontario Hydro and AECL facilities at a total cost of billions of dollars.

The dose level would fall to a weighted average of 0.0104 mSv resulting in the saving of 0.29 lives over the population exposed over a 70 year period.

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APPENDIX A

Tables Of Data

Table A.1

Water Treatment Plant	Population	Households Served	Source of Water Supply
Kincardine	2,864	1,378	Lake Huron
Port Elgin	5,909	2,731	Lake Huron
Bowmanville	13,750	N/A	Lake Ontario
Newcastle	37,769	16,875	Lake Ontario
R.C. Harris	712,679	895,235	Lake Ontario
Horgan (Scarborough)	631,957	895,235	Lake Ontario
Ajax - W.A. Parish	45,046	18,359	Lake Ontario
Oshawa	120,904	48,354	Lake Ontario
Whitby	49,948	20,119	Lake Ontario
Amherstberg	8,211	3,233	Lake Michigan
Harrow-Colchester	7,210	3,346	Lake Michigan
Wheatley	1,539	593	Lake Michigan
Petawawa	7,905	1,611	Ottawa River
Deep River	4,166	1,798	Ottawa River
Pembroke	13,595	5,994	Ottawa River
Rolphton	N/A	N/A	Ottawa River
Lorne Park	700,000	N/A	Lake Ontario

N/A: Not available

SOURCE: Ontario Hydro Ref #16.
Municipal Financial Information 1991.

Table A.2
Average of Weekly/Monthly and Maximum Tritium Concentrations At WTP

Water Treatment Plant	Months of Data (#)		Average (Bq/L)		Maximum Value (Bq/L)		Standard Deviation of Moving Annual Average (Bq/L)		Ratio of Maximum to Average	
	OH	MOL	OH	MOL	OH	MOL	OH	MOL	OH	MOL
Kincardine	132	66	14.2	9.0*	443.3	29*	5.1	1.6	31.2	3.2*
Port Elgin	132	40	48.5	49.4*	732.6	300*	14.4	17.7	15.1	6.1*
Ajax W.A. Parish	113	69	30.9	20.3	322.6	220	17.3	3.6	10.4	10.8
Bowmanville	96	63	10.2	10.4	120.6	30	7.4	0.8	11.8	2.9
Newcastle	96	62	10.1	10.5	89.2	77	7.5	0.6	8.8	7.3
Oshawa	132	69	19.8	13.5	176.5	75	8.4	1.1	8.9	5.6
Whitby	54	62	5.3	12.5	105.5	210	6.5	2.6	19.9	16.8
R.C. Harris	132	71	13.6	10.0	195.4	180	3.5	2.2	14.4	18
R.L. Clark	N/M	70	N/M	9.6	N/M	73	N/M	1.9	N/M	7.6
Horgan	132	71	14.4	9.8	159.8	150	4.7	1.8	11.1	15.3
Amherstburg	N/M	54	N/M	6.1*	N/M	34*	N/M	1.7	N/M	5.6*
Harrow-Colchester	N/M	52	N/M	5.7*	N/M	12*	N/M	0.6	N/M	2.1*
Wheatley	N/M	54	N/M	5.5*	N/M	12*	N/M	0.6	N/M	2.2*
Petawawa	N/M	39	N/M	10.7*	N/M	33*	N/M	2.4	N/M	3.1*
Deep River	N/M	54	N/M	6.8*	N/M	41*	N/M	1.7	N/M	6.0*
Pembroke	N/M	52	N/M	11.2*	N/M	120*	N/M	5.1	N/M	10.7*
Rolphton	N/M	51	N/M	6.6*	N/M	64*	N/M	2.3	N/M	9.7*
Lakeview	N/M	21	N/M	8.7	N/M	15	N/M	0.3	N/M	1.7
Lorne Park	N/M	21	N/M	8.6	N/M	14	N/M	0.2	N/M	1.6

*** Denotes average of monthly values**
N/M Denotes not monitored
SOURCE: Ontario Hydro Correspondence - July 12, 1994, Ministry of Labour, Radiation Protection Service

Table A.3
SUMMARY OF TRITIUM EMISSIONS TO WATER
TBq*/y

SOURCES OF TRITIUM	1993		1992		1991	
	TOTAL	% OF TOTAL	TOTAL	% OF TOTAL	TOTAL	% OF TOTAL
PICKERING A&B						
Condenser Cooling Water	240	43.1	350	11.6	280	66.2
Up Processing Plant-B Cooling Water	28	5.0	22	0.7	2.9	0.7
Up Processing Plant-A Cooling Water	33	5.9	46	1.5	4.2	1.0
SEWAGE	.23	0.0	.3	0.0	1.2	0.3
Reactor Building Service Water	250	45.6	2,600	86.0	130	30.6
Auxiliary Irradiated Fuel Bag	.21	0.0	.084	0.0	.27	0.1
SULZER-A[1]	1.2	0.2	2.7	0.1	.4	0.1
SULZER-B[1]	.7	0.1	3.4	0.1	4.8	1.1
SUBTOTAL	553.34	100.0	3,024.48	100.0	423.77	100.0
BRUCE A						
REGULAR[2]	1,100	71.2	920	54.8	800	28.6
IRREGULAR[3]	430	28.8	760	45.2	2,000	71.4
SUBTOTAL	1,530.00	100.0	1,680.00	100.0	2,800.00	100.0
BRUCE B						
REGULAR[2]	530	79.7	410	100.0	580	100.0
IRREGULAR[3]	130	20.3				
SUBTOTAL	660.00	100.0	410.00	100.0	580.00	100.0
DARLINGTON						
SUBTOTAL	57	100.0				
TOTAL	2,800.34		5,114.48		3,803.77	

* 1 TBq = 1 x 10^{12} Bq

[1] Moderator Water Upgrade Cooling Water.

[2] Regular Source due to Minor Leakages.

[3] Irregular Source due to Equipment Failure.

SOURCE: Ontario Hydro Submission Ref #8.

Table A.4
ONTARIO HYDRO EMISSION LIMITS FOR TRITIUM IN WATER

	Pickering A	Pickering B	Darlington	Bruce A	Bruce B
Derived Emission Limit (DEL), TBq*/y	620,000	620,000	5,300,000	1,700,000	3,000,000
Operating Target, TBq/y (based on 1% DEL)	6,200	6,200	53,000	17,000	30,000
CCW full power cooling flow, L/y**	3 trillion	3 trillion	4.5 trillion	4.8 trillion	4.9 trillion
Derived Liquid Concentration, Bq/L	210,000	210,000	1,200,000	350,000	610,000
Operating Target, Bq/L (based on 1% DEL)	2,100	2,100	12,000	3,500	6,100

[*] 1 TBq = 10^{12} Bq

[**] Note: In Normal operation, actual cooling water flow may be lower than this maximum value, providing smaller dilution factors.

SOURCE: Ontario Hydro Submission Ref #8.

Table of weekly and annual means and current exceedences of 7,000, 100 and 20 for each WTP.

Table A.4.1
AECL EMISSION LIMITS FOR TRITIUM IN WATER

	NPD	CRL
Derived Release Limit (DRL), TBq*/y	10,800	36,000

SOURCE: AECL Submission Ref #17.

TABLE A.5

Water Treatment Plant	Population	Costs Associated With Alternative Sources of Water When Exceedence of Tritium Exists For 14 Days
Kincardine	2,864	$40,096
Port Elgin	5,909	$82,726
St. Mary's Cement Plant	N/A	N/A
Bowmanville	13,750	$192,500
Newcastle	37,769	$528,766
R.C. Harris	712,679	$9,977,506
Horgan (Scarborough)	631,957	$8,847,398
Ajax - W.A. Parish	45,046	$630,644
Oshawa	120,904	$1,692,656
Whitby	49,948	$699,272
Amherstberg	8,211	$114,954
Harrow-Colchester	7,210	$100,940
Wheatley	1,539	$21,546
Petawawa	7,905	$110,670
Deep River	4,166	$58,324
Pembroke	13,595	$190,330
Rolphton	N/A	N/A
Lorne Park	700,000	$9,800,000

N/A: Not available

SOURCE: Municipal Financial Information 1991.
Ministry of Environment and Energy estimates based on $1 per person per day.

Table A.6.1

EMISSION REDUCTIONS FACTORS AS A RESULT OF APPLYING 5E-6 OR 1E-6 RISK LIMITS TO ALL ONTARIO HYDRO RADIOACTIVE EMISSIONS (BASED ONLY ON 1993 DATA)

Radionuclide/ Emission Pathway	**Single or Multiple Pathway**	**Emission Reduction Factor Required for Risk = 5E-6**			**Emission Reduction Factor Required for Risk = 1E-6**		
		DNGS	**PNBS**	**BNPD**	**DNGS**	**PNGS**	**BNPD**
Noble Gas/Air	S	NA	6.7	1.5	4.5	34	7
Carbon-14/AIR	S	NA	2.2	NA	1.6	11	4
Tritium/AIR	S	NA	1.8	1.2	NA	9	6
Tritium/WATER	S	NA	NA	NA	NA	NA	2.8
PARTICULATE/AIR	S	NA	NA	NA	NA	NA	1.1
PARTICULATE/WATER	S	NA	NA	NA	NA	NA	1.2
Noble Gas	M	NA	6.7	1.5	4.6	34	7
Carbon-14	M	NA	2.2	NA	2.2	11	4.4
Tritium	M	NA	2.3	2.1	1.4	12	10.4
PARTICULATE	M	NA	NA	NA	NA	NA	2.4

Note: The above factors assume that background radioactivity is not included. If background is include (as required for drinking water), these factors will increase.

For C-14, the natural background level of about 250 Bq/kg-C already exceeds the maximum concentration that would be allowed for a lifetime risk level of 5E-6 for milk, fruits and vegetables. For the risk level of 1E-6, natural background would exceed the maximum concentrations for mild, fruits, vegetables and fish.

Source: Ontario Hydro Submission Ref #8.

Table A.6.2
IMPACT OF ACES RECOMMENDATION ON ALL RADIONUCLIDES AND PATHWAYS

Nuclide	Average Annual Release Rate (Bq/s)	Fraction of Current DRL	Fraction of 20 Bq/L Equivalent Dose[1]
Airborne:			
Noble Gases	2.09E+07	0.0162	280
Tritium	2.91E+05	0.0008	14
I-131	5.42E+00	0.0008	14
I-125	5.58E+00	0.0013	23
Beta/Gamma Particulates	6.56E-02	0.0000	0.02
Liquid:			
Tritium	4.22E+06	0.00458	79.1
Sr-90	4.18E+02	0.00009	1.6
Cs-137	1.11E+02	0.00039	6.8
As-76	7.38E+03	0.00106	19.3
Na-24	4.41E+04	0.00063	10.9
Co-60	1.17E+02	0.00084	14.5

[1] Reduction needed in current emissions to meet a dose limit equivalent to that for tritium at 20 Bq/L

SOURCE: AECL Submission Ref #17.

Table A.7
Estimated Long Term Average Tritium Concentration @100 Bq/L and 20 Bq/L

Water Treatment Plant	Months of Data (#)		Long term Average (Bq/L)		Long term Average @ 100 Bq/L		Long term Average @ 20 Bq/L	
	OH	MOL	OH	MOL	OH	MOL	OH	MOL
Kincardine	132	66	14.2	9.0*	13.3	9.0*	10.9	8.5*
Port Elgin	132	40	48.5	49.4*	36.3	38.2*	15.6	15.8*
Ajax W.A. Parish	113	69	30.9	20.3	25.0	19.6	13.9	12.9
Bowmanville	96	63	10.2	10.4	10.1	10.4	8.1	10.2
Newcastle	96	62	10.1	10.5	10.1	10.5	7.9	10.0
Oshawa	132	69	19.8	13.5	18.8	13.5	12.9	11.5
Whitby	54	62	5.3	12.5	5.2	11.8	4.6	10.6
R.C. Harris	132	71	13.6	10.0	13.4	9.7	11.6	9.2
R.L. Clark	N/M	70	N/M	9.6	N/M	9.6	N/M	8.9
Horgan	132	71	14.4	9.8	14.2	9.6	11.8	9.2
Amherstburg	N/M	54	N/M	6.1*	N/M	6.1*	N/M	5.8*
Harrow-Colchester	N/M	52	N/M	5.7*	N/M	5.7*	N/M	5.7*
Wheatley	N/M	54	N/M	5.5*	N/M	5.5*	N/M	5.5*
Petawawa	N/M	39	N/M	10.7*	N/M	10.7*	N/M	9.9*
Deep River	N/M	54	N/M	6.8*	N/M	6.8*	N/M	6.0*
Pembroke	N/M	52	N/M	11.2*	N/M	10.5*	N/M	8.8*
Rolphton	N/M	51	N/M	6.6*	N/M	6.6*	N/M	5.6*
Lakeview	N/M	21	N/M	8.7	N/M	8.7	N/M	8.7
Lorne Park	N/M	21	N/M	8.6	N/M	8.6	N/M	8.6
St. Mary's Cement Plant	59	N/M	6.6	N/M	6.5	N/M	4.9	N/M

*** Denotes average of monthly values**
N/M denotes not monitored
SOURCE: Ontario Hydro (OH) Correspondence - July 12, 1994, Ministry of Labour (MOL), Radiation Protection Service

Table A.8
ESTIMATED DOSE AND RISK OF CANCER IF TRITIUM LEVELS >100 Bq/L

WATER TREATMENT PLANT	POPULATION	>100 Bq/L 10 YEAR AVERAGE (Bq/L)	DOSE (mSv)	RISK	RISK REDUCTION FROM HISTORICAL EXPOSURE[1]	THEORETICAL NUMBER OF LIVES SAVED OVER A LIFETIME
Kincardine	2,864	13.3	0.013593	6.8E-07	4.6E-08	0.0
Port Elgin	5,909	36.3	0.037099	1.9E-06	6.2E-07	0.004
Bowmanville	13,750	10.1	0.010322	5.2E-07	5.1E-09	0.0
Newcastle	37,769	10.1	0.010322	5.2-07	0	0.0
R.C. Harris	712,679	13.4	0.013695	6.8E-07	1.0E-08	0.007
R.L. Clark	988,654	9.6	0.009811	4.9E-07	0	0.0
Horgan	631,957	14.2	0.014512	7.3E-07	1.0E-08	0.006
Ajax	45,046	25.0	0.025550	1.3E-06	3.0E-07	0.014
Oshawa	120,904	18.8	0.019214	9.6E-07	5.1E-08	0.006
Whitby	49,948	11.8	0.012060	6.0E-07	3.6E-08	0.002
Amherstburg	15,951	6.1	0.006234	3.1E-07	0	0.0
Horrow-Colchester	3,537	5.7	0.005825	2.9E-07	0	0.0
Wheatley	1,539	5.5	0.005621	2.8E-07	0	0.0
Petawawa	4,500	10.7	0.010935	5.5E-07	0	0.0
Deep River	7,914	6.8	0.006950	3.5E-07	0	0.0
Pembroke	16,000	10.5	0.010731	5.4E-07	3.6E-08	0.001
Rolphton	N/A	6.6	0.006745	3.4E-07	0	N/A
Lakeview	700,000	8.7	0.008891	4.4E-07	0	0.0
Lorne Park	700,000	8.6	0.008789	4.4E-07	0	0.0
TOTAL	3,358,921.00					0.04

[1] Fatal Cancer Risk per person exposed

Assumptions: 2 litres of water consumed/day 365 days/year
Dose conversion factor 2.0 x 10^{-8} mSv/Bq
Risk of fatal cancer/mSv 5×10^{-5}

N/A: Not available

SOURCE: Municipal Financial Information 1991, Ministry of Environment and Energy Calculations.

Table A.9
ESTIMATED DOSE AND RISK OF CANCER AT TRITIUM LEVELS >20 Bq/L

WATER TREATMENT PLANT	POPULATION	>20 Bq/L 10 YEAR AVERAGE (Bq/L)	DOSE (mSv)	RISK	RISK REDUCTION FROM HISTORICAL EXPOSURE[1]	THEORETICAL NUMBER OF LIVES SAVED
Kincardine	2,864	10.9	0.011140	5.6E-07	1.7E-07	0.0
Port Elgin	5,909	15.6	0.015943	8.0E-07	1.7E-06	0.010
Bowmanville	13,750	8.1	0.008278	4.1E-07	1.1E-07	0.002
Newcastle	37,769	7.9	0.008074	4.0E-07	1.1E-07	0.004
R.C. Harris	712,679	11.6	0.011855	5.9E-07	1.0E-07	0.071
R.L. Clark	988,654	8.9	0.009096	4.5E-07	3.6E-08	0.036
Horgan	631,957	11.8	0.012060	6.0E-07	1.3E-07	0.082
Ajax	45,046	13.9	0.014206	7.1E-07	8.7E-07	0.039
Oshawa	120,904	12.9	0.013184	6.6E-07	3.5E-07	0.042
Whitby	49,948	10.6	0.010833	5.4E-07	9.7E-08	0.005
Amherstburg	15,951	5.8	0.005928	3.0E-07	1.5E-08	0.0
Horrow-Colchester	3,537	5.7	0.005825	2.9E-07	0	0.0
Wheatley	1,539	5.5	0.005621	2.8E-07	0	0.0
Petawawa	4,500	9.9	0.010118	5.1E-07	4.1E-08	0.0
Deep River	7,914	6.0	0.006132	3.1E-07	4.1E-08	0.0
Pembroke	16,000	8.8	0.008994	4.5E-07	1.2E-07	0.002
Rolphton	N/A	5.6	0.005723	2.9E-07	5.1E-08	N/A
Lakeview	700,000	8.7	0.008891	4.4E-07	0	0.0
Lorne Park	700,000	8.6	0.008789	4.4E-07	0	0.0
TOTAL	3,358,921.00					0.29

[1] Fatal Cancer Risk per person exposed

Assumptions: 2 litres of water consumed/day 365 days/year
Dose conversion factor 2.0×10^{-8} mSv/Bq
Risk of fatal cancer/mSv 5×10^{-5}

N/A: Not available

SOURCE: Municipal Financial Information 1991, Ministry of Environment and Energy Calculations.

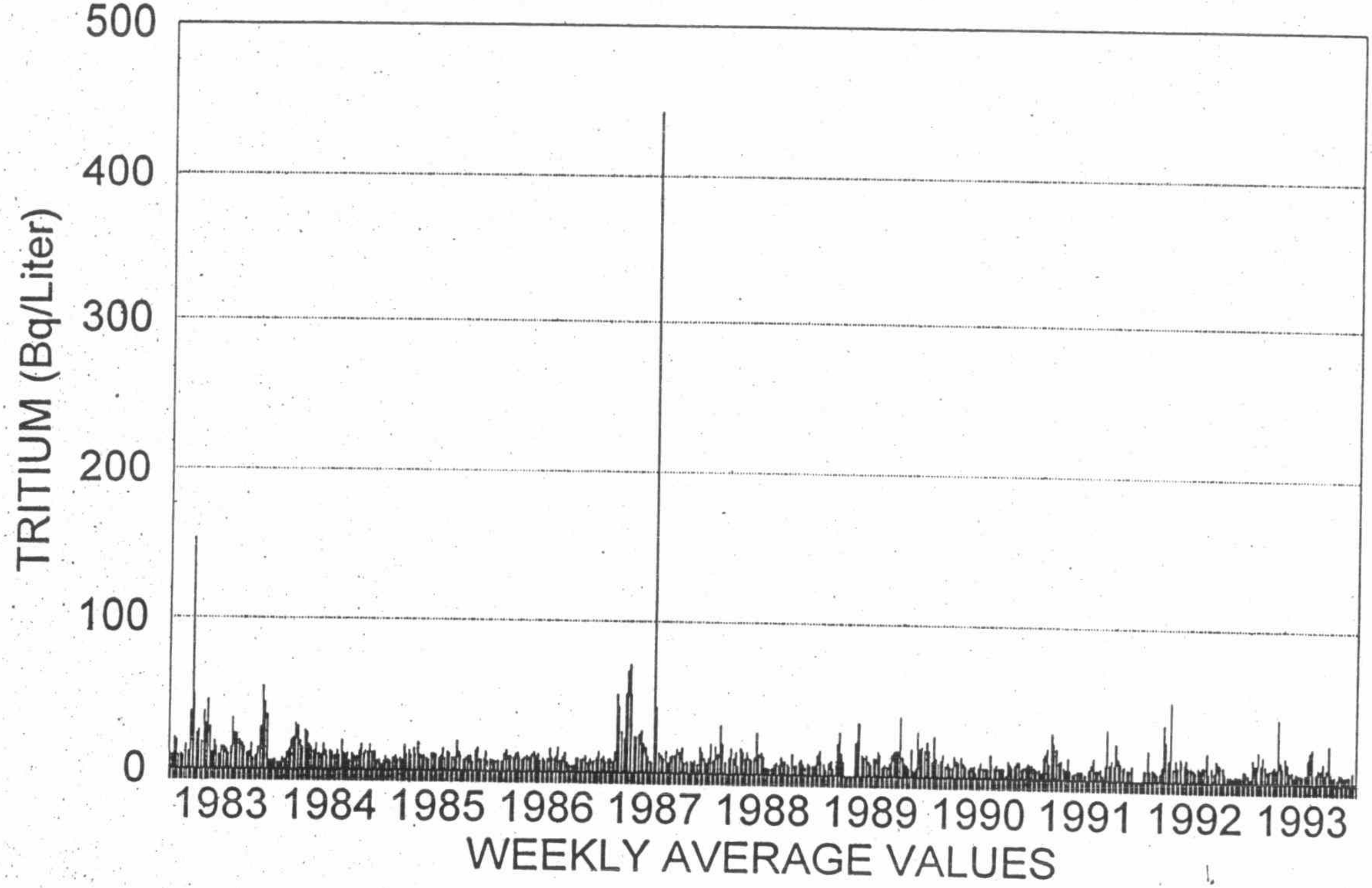
APPENDIX B

Time Series Data for Tritium Concentrations at Water Treatment Plants near Ontario Hydro Facilities

KINCARDINE WSP

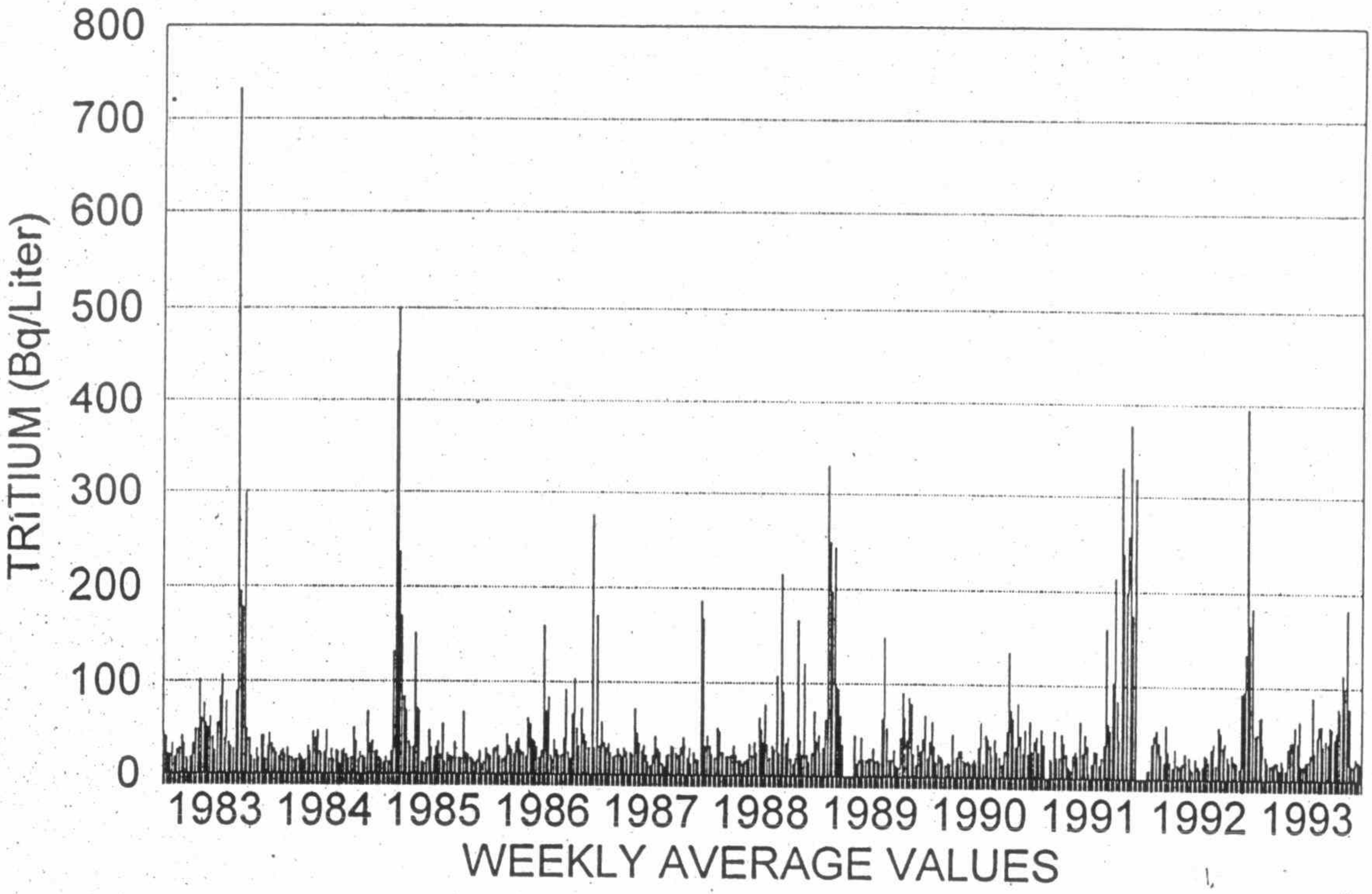
DRINKING WATER

KINCARDINE



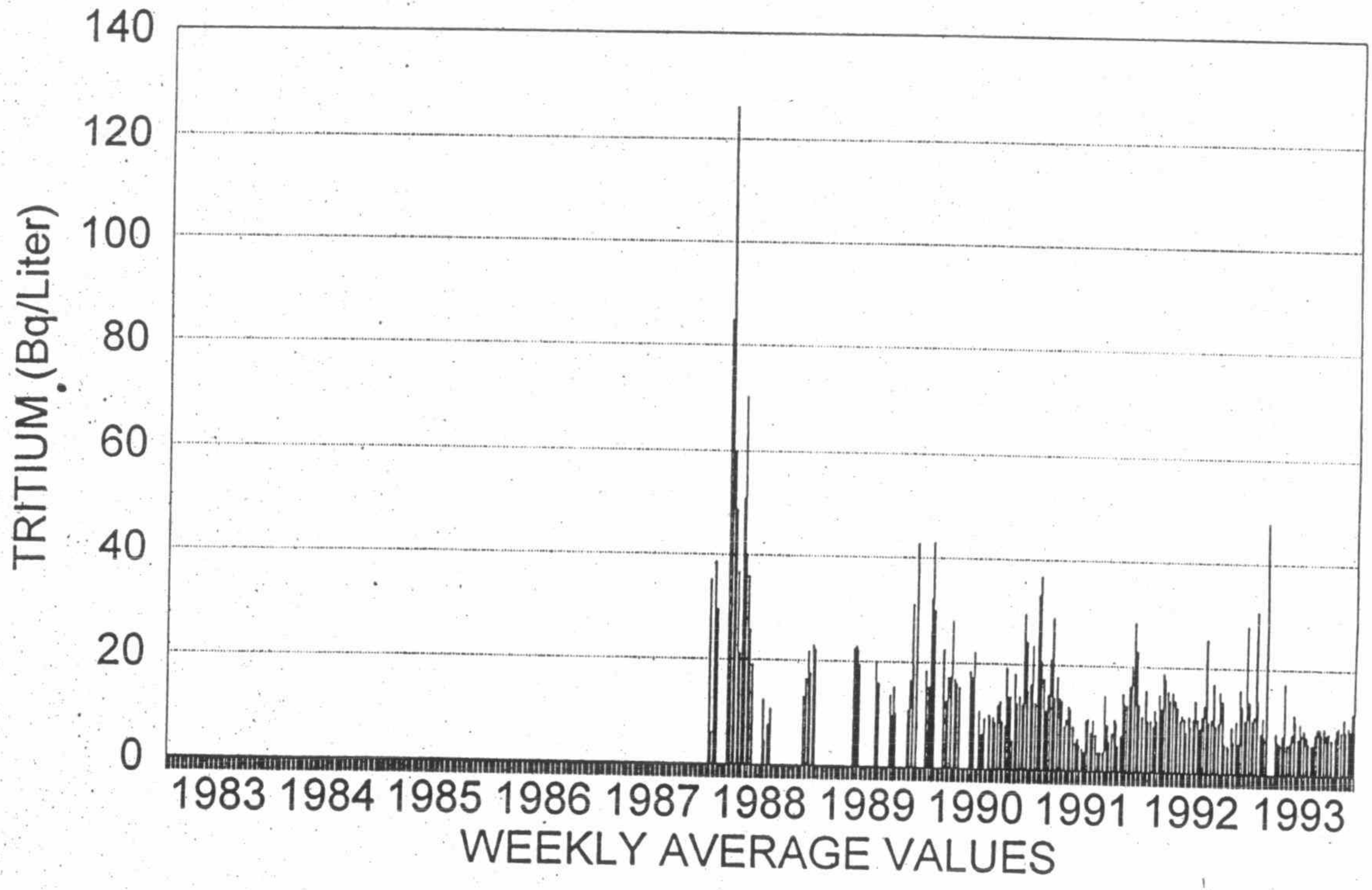
PORT ELGIN WSP

DRINKING WATER

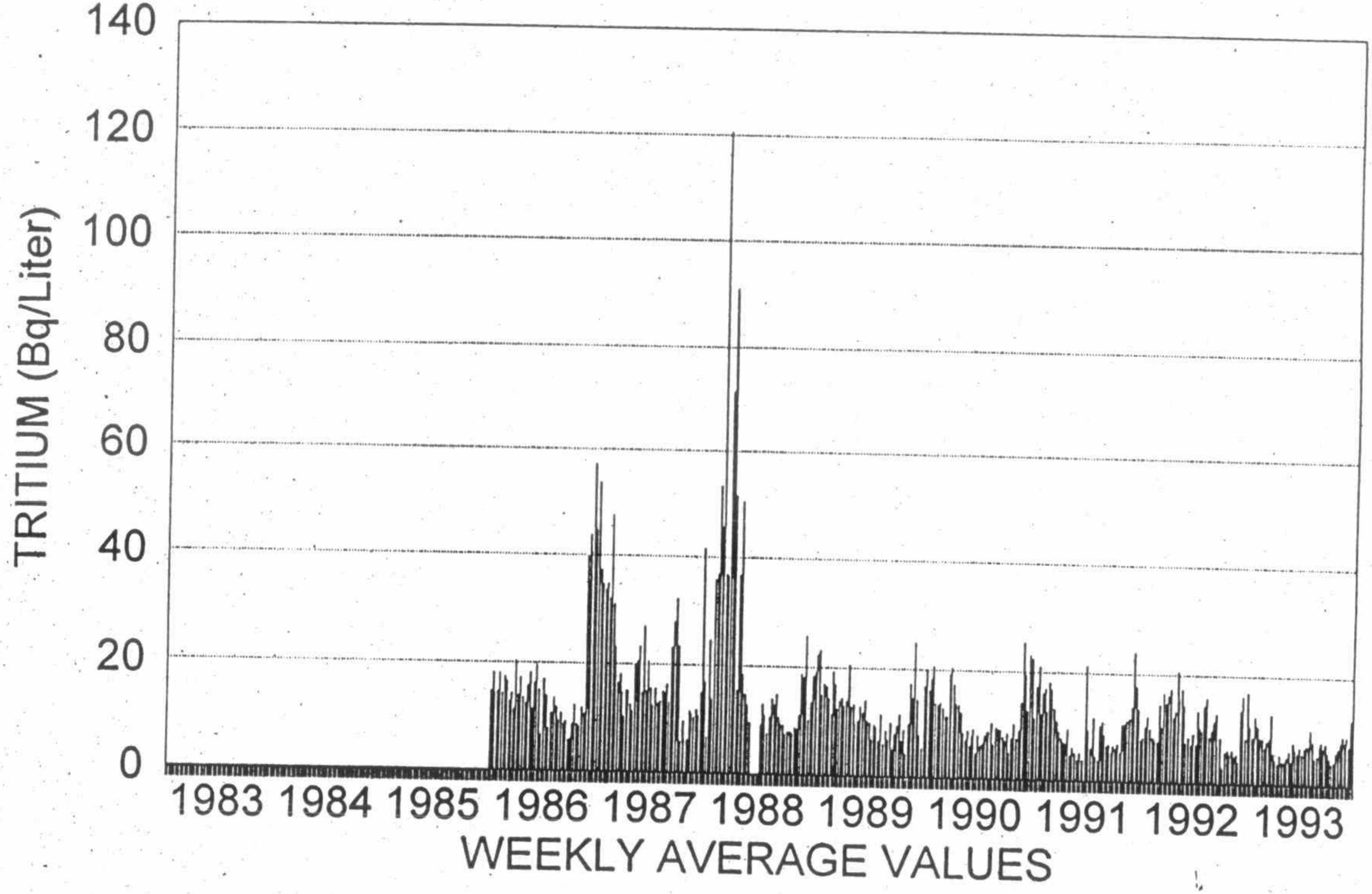


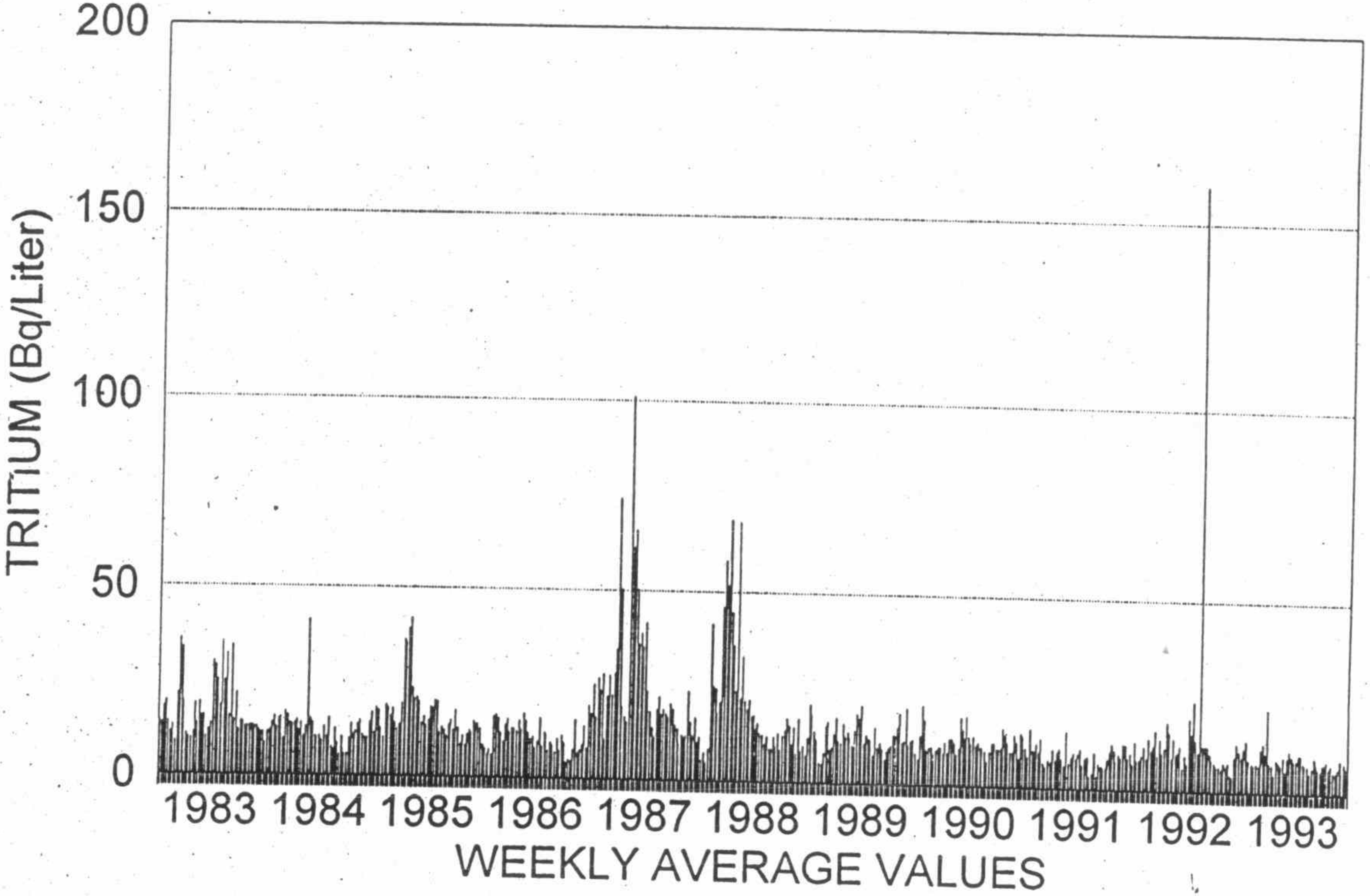
ST. MARY'S CEMENT PLANT

DRINKING WATER



BOWMANVILLE WSP
DRINKING WATER





SCARBOROUGH WSP

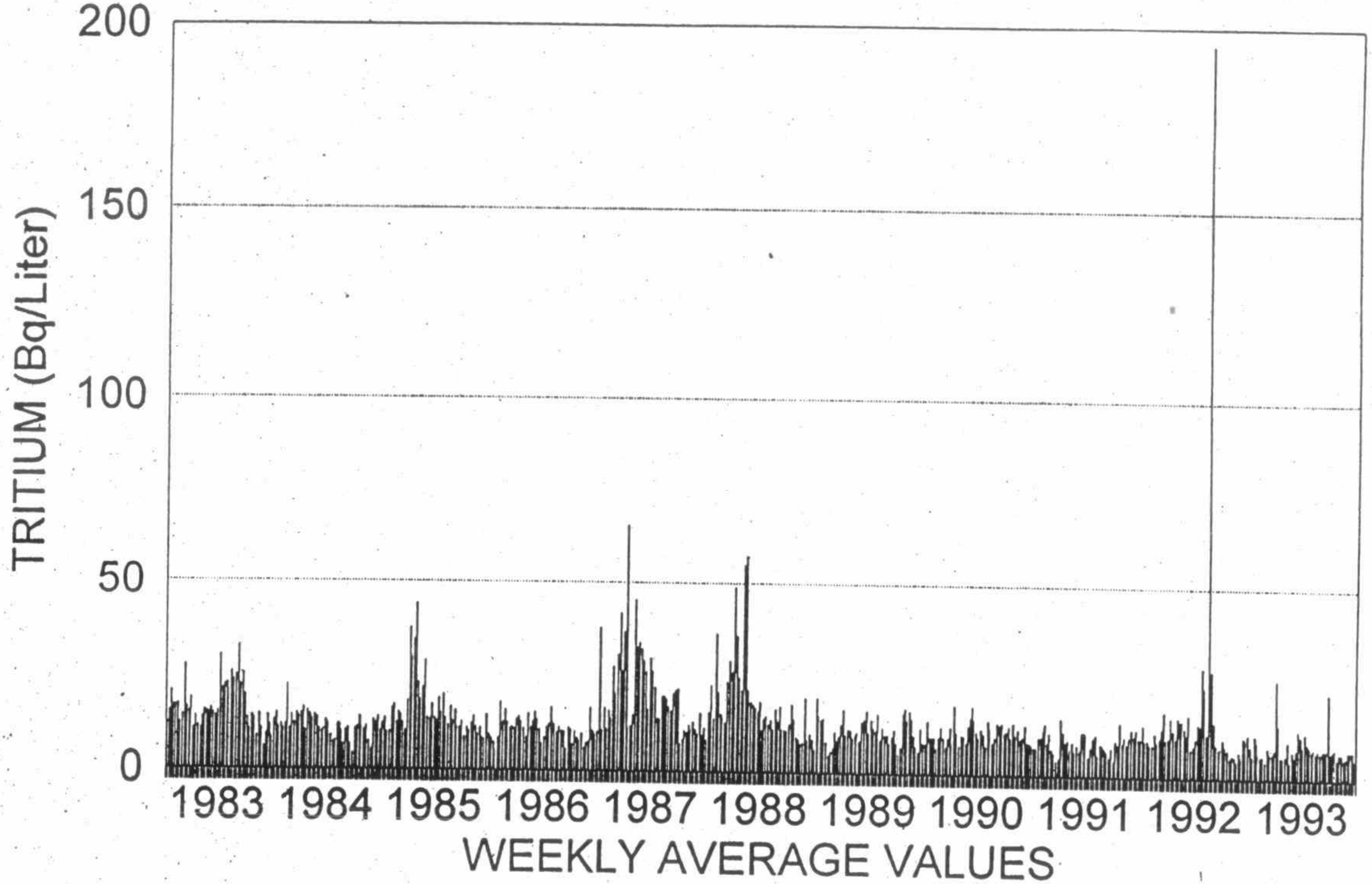
DRINKING WATER

SCARBOROUGH

B5

R.C. HARRIS WSP (TORONTO)

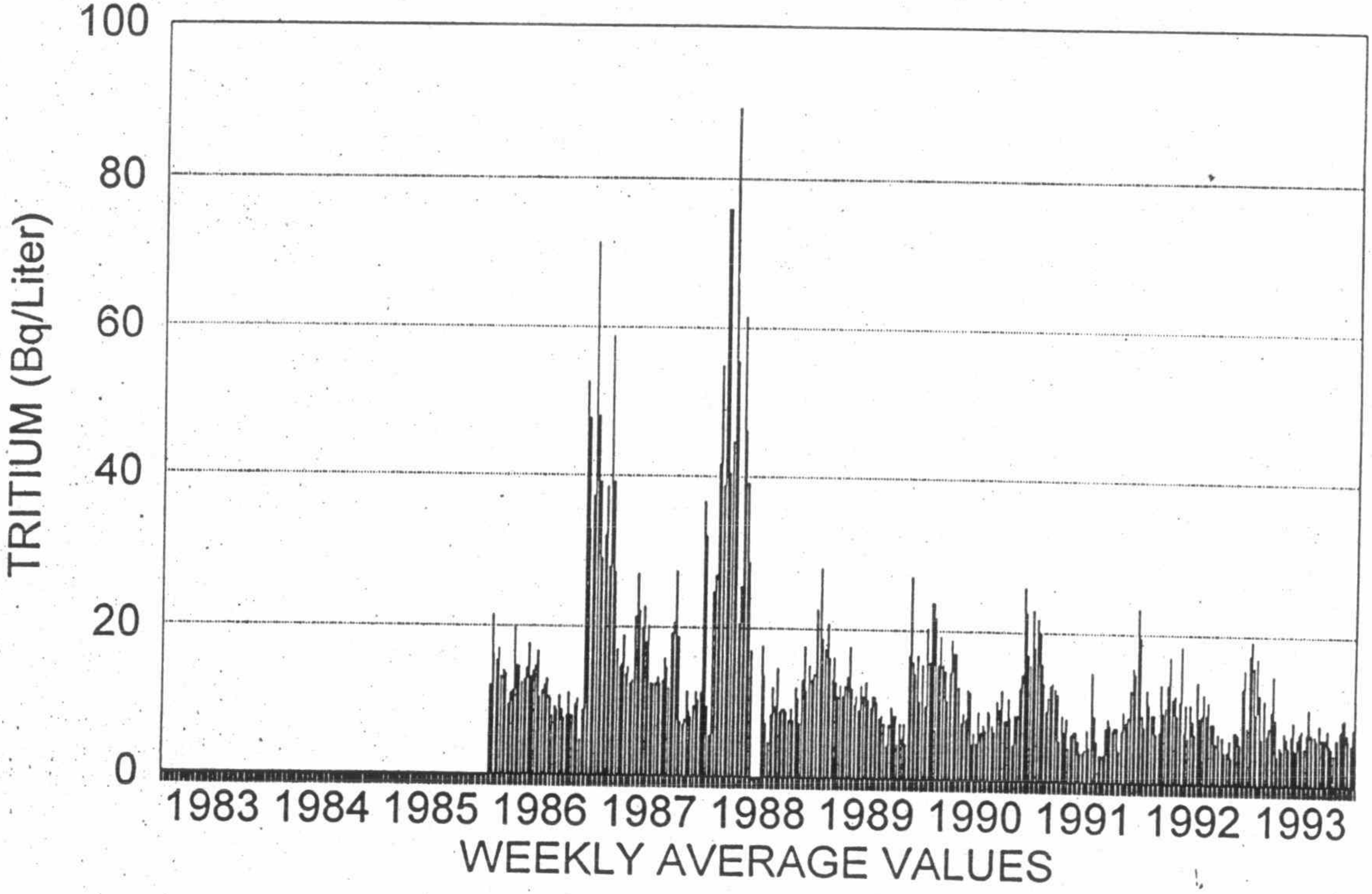
DRINKING WATER



NEWCASTLE WSP

DRINKING WATER

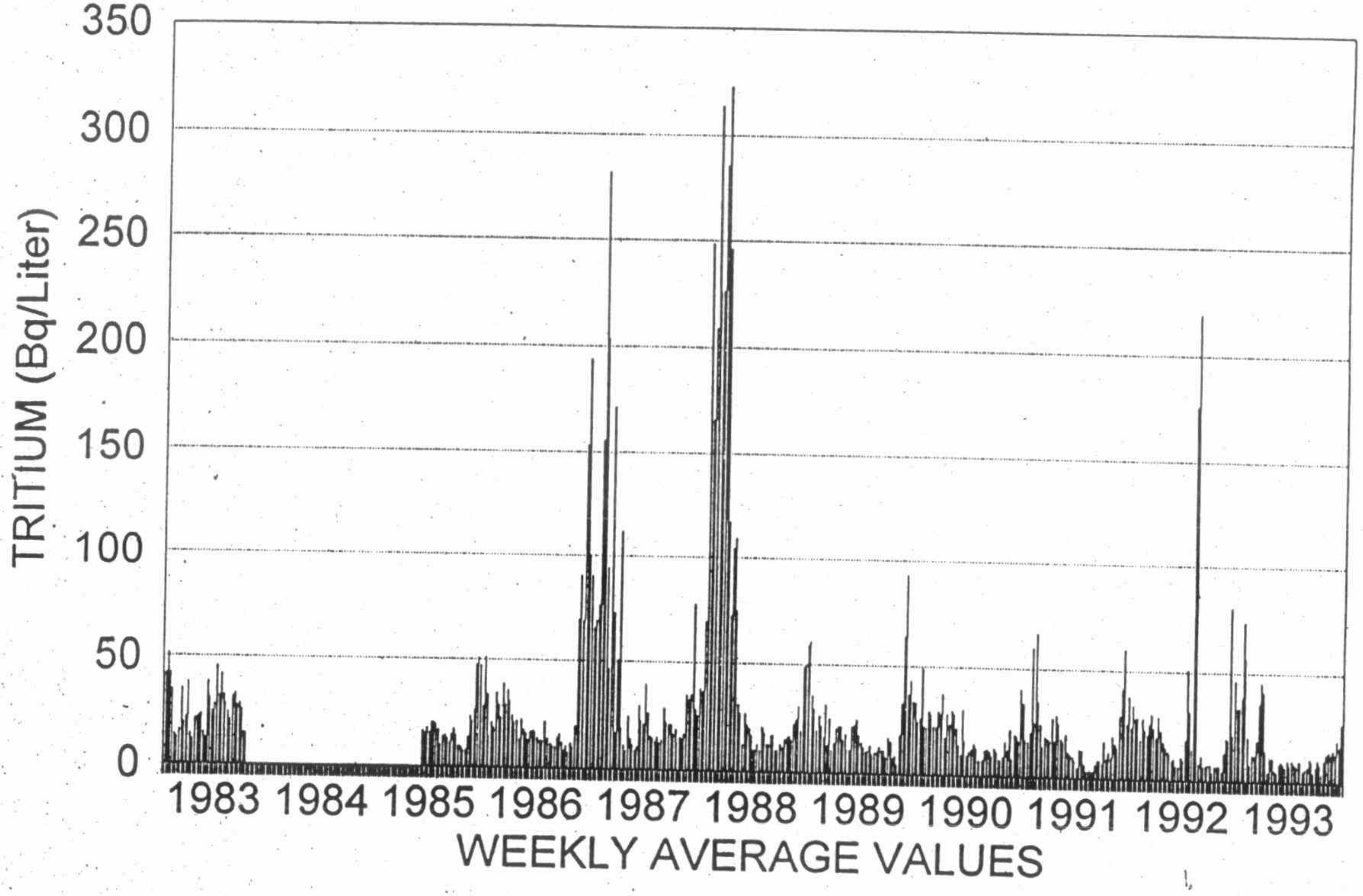
NEWCASTLE



B7

AJAX WSP

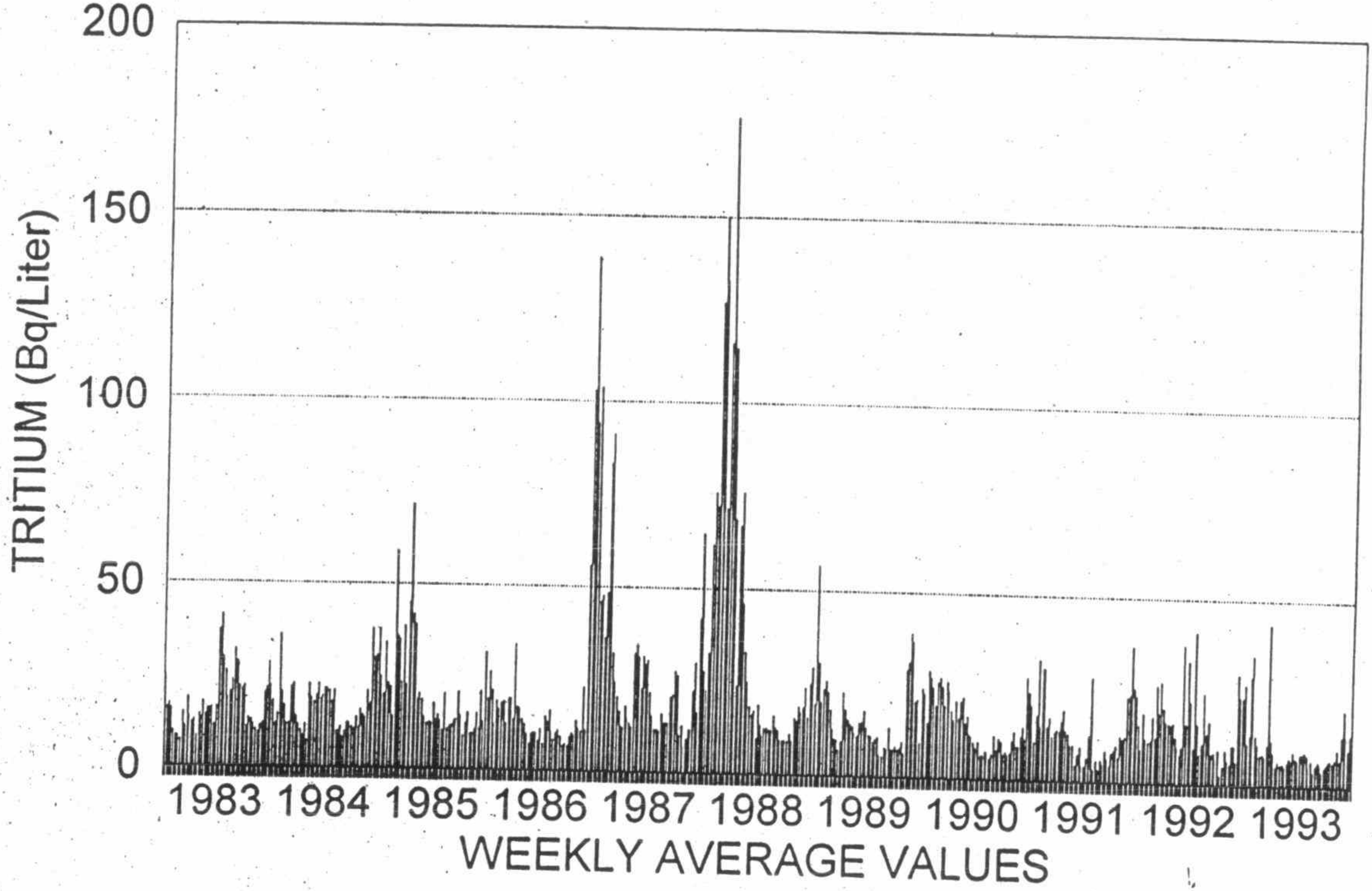
DRINKING WATER



OSHAWA WSP

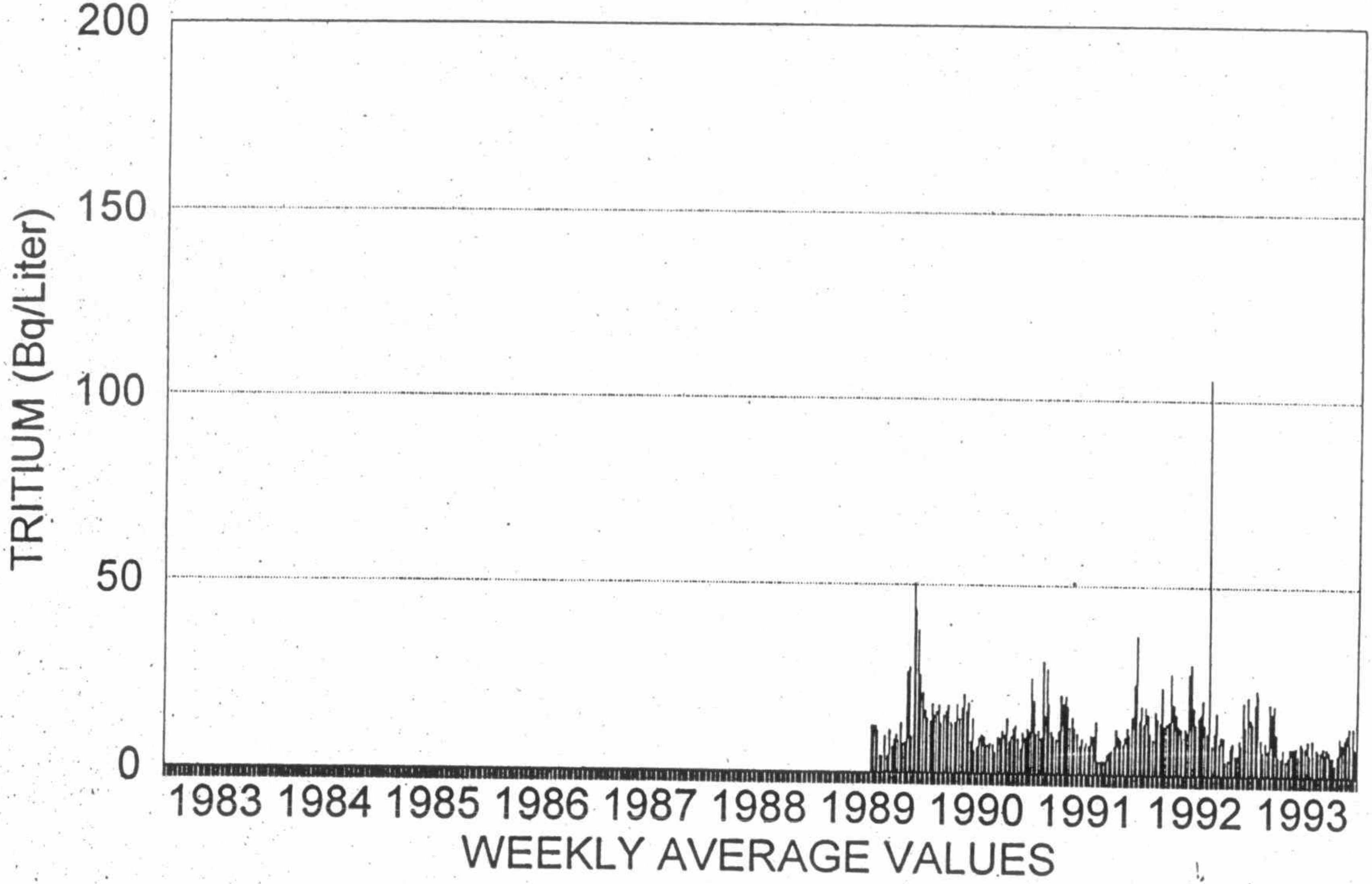
DRINKING WATER

OSHAWA



WHITBY WSP

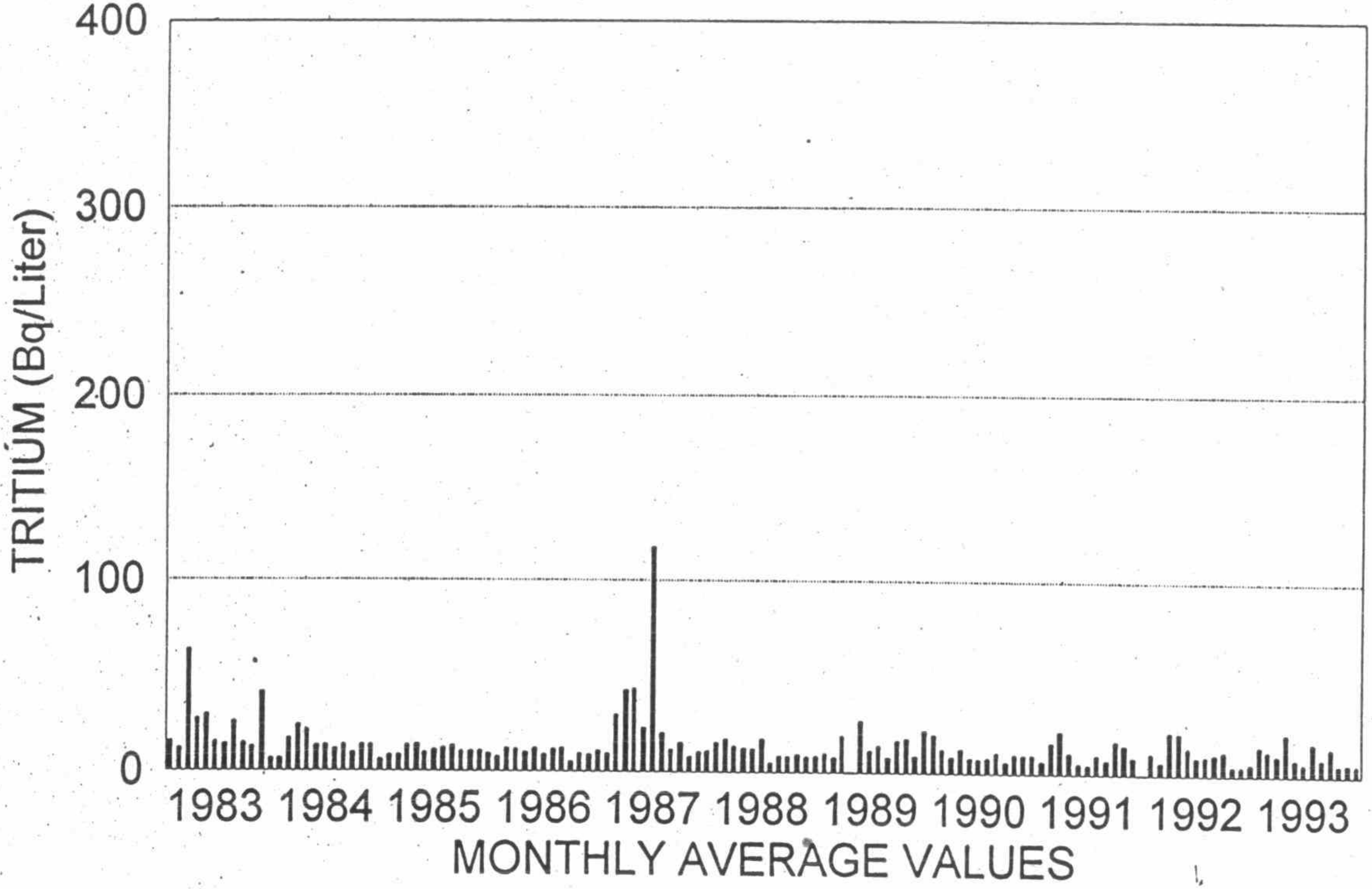
DRINKING WATER



KINCARDINE WSP

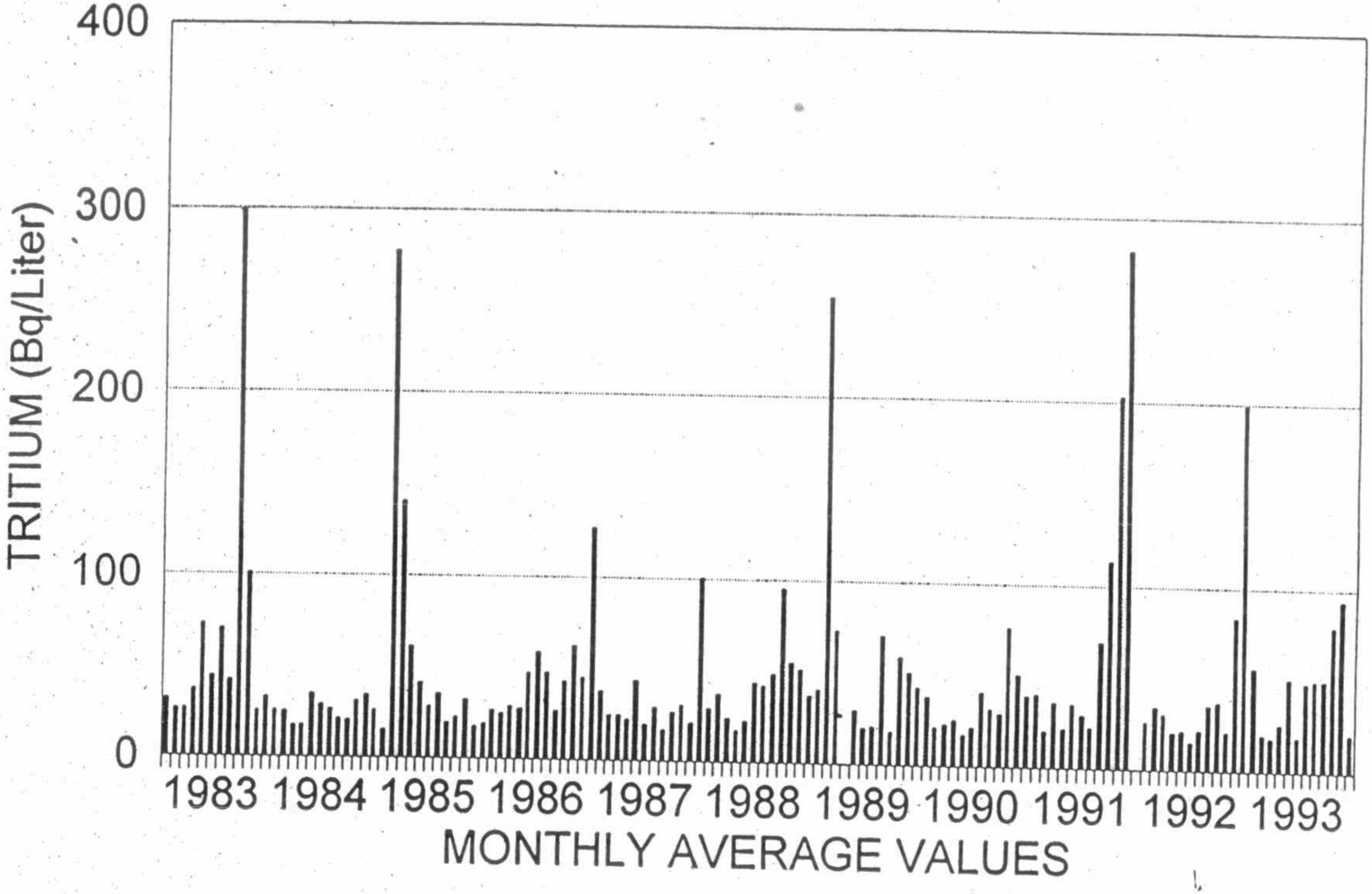
DRINKING WATER

KINCARDINE



PORT ELGIN WSP

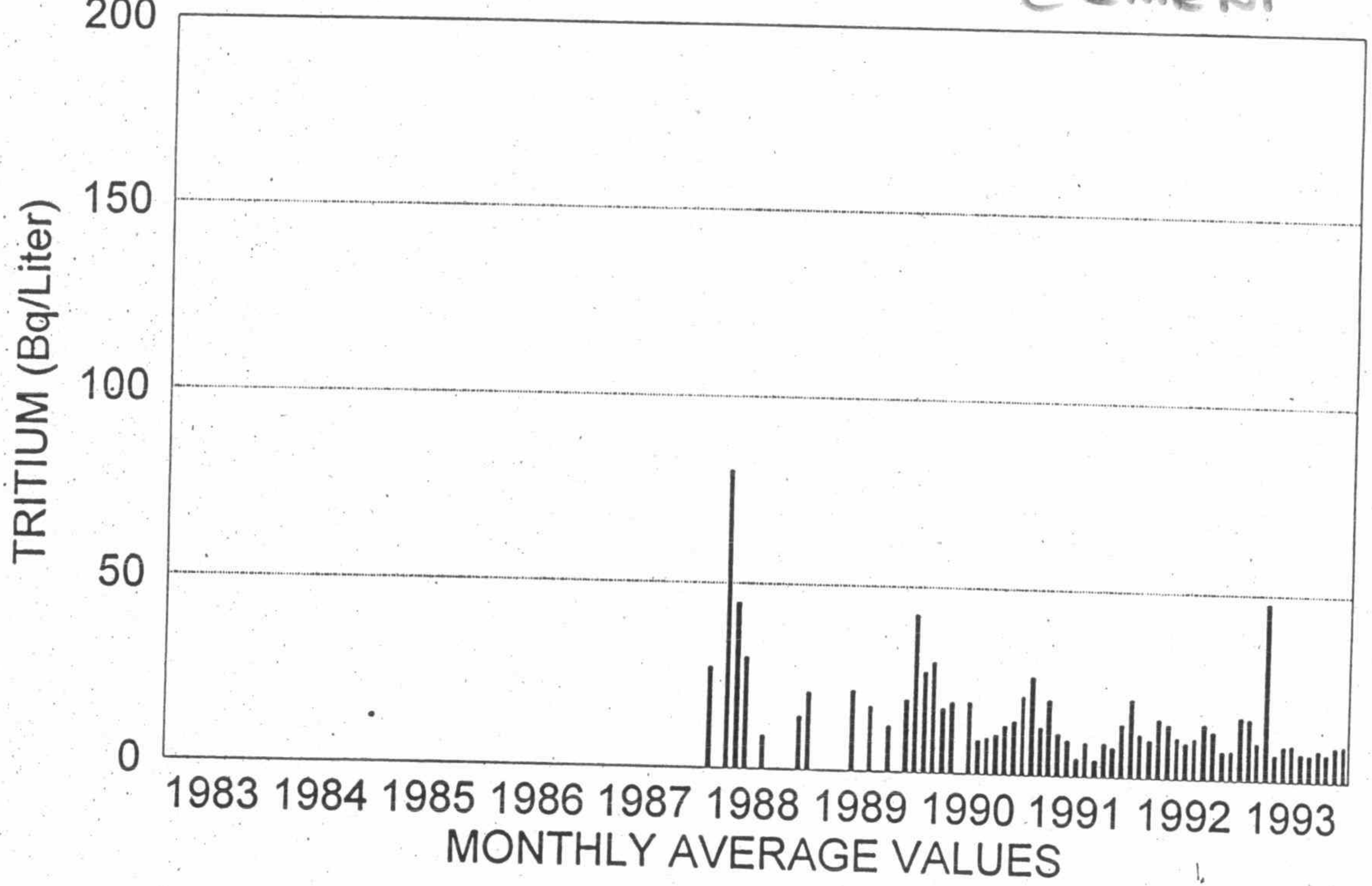
DRINKING WATER



ST. MARY'S CEMENT PLANT

DRINKING WATER

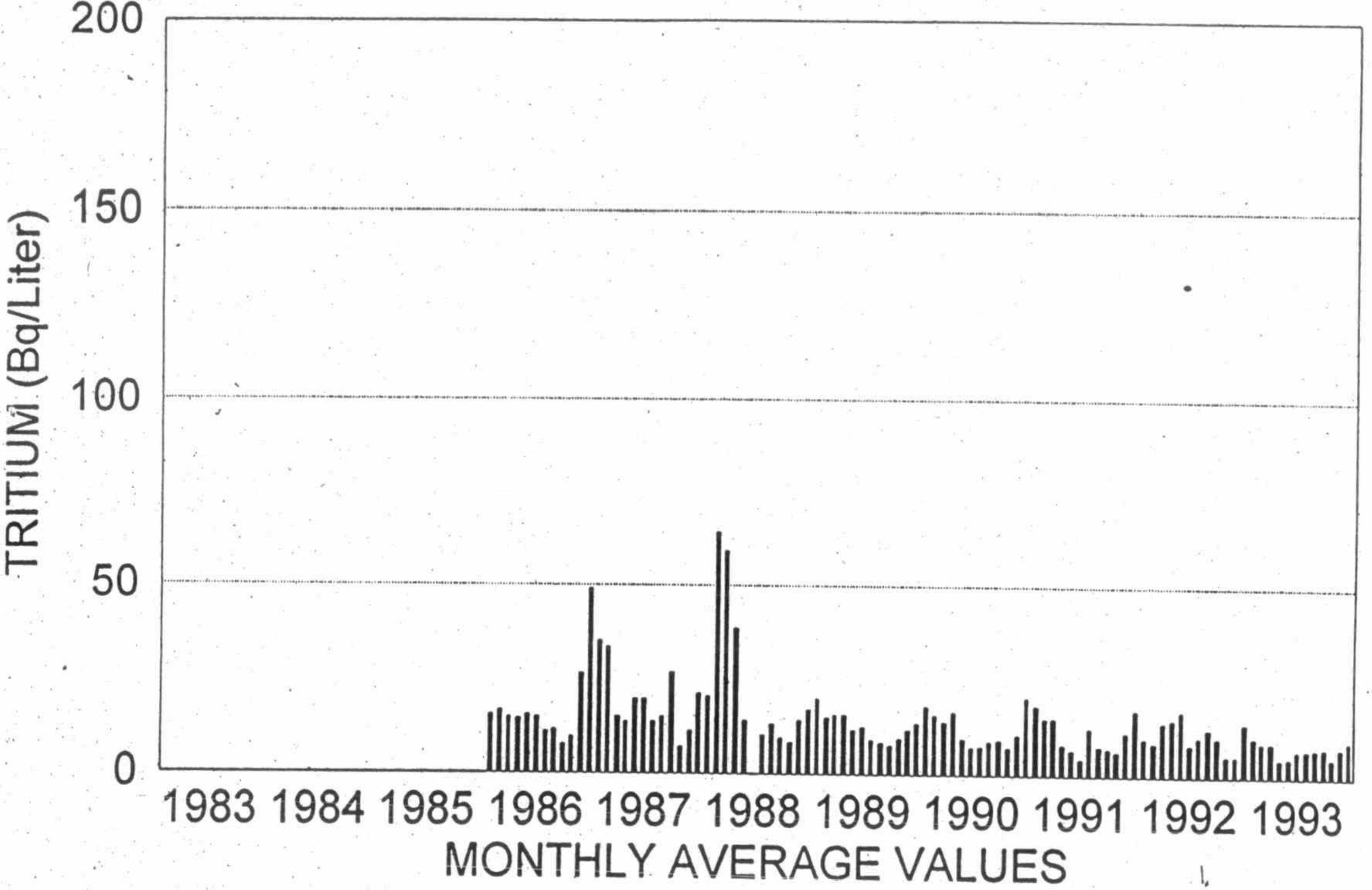
ST. MARY'S
CEMENT



B13

BOWMANVILLE

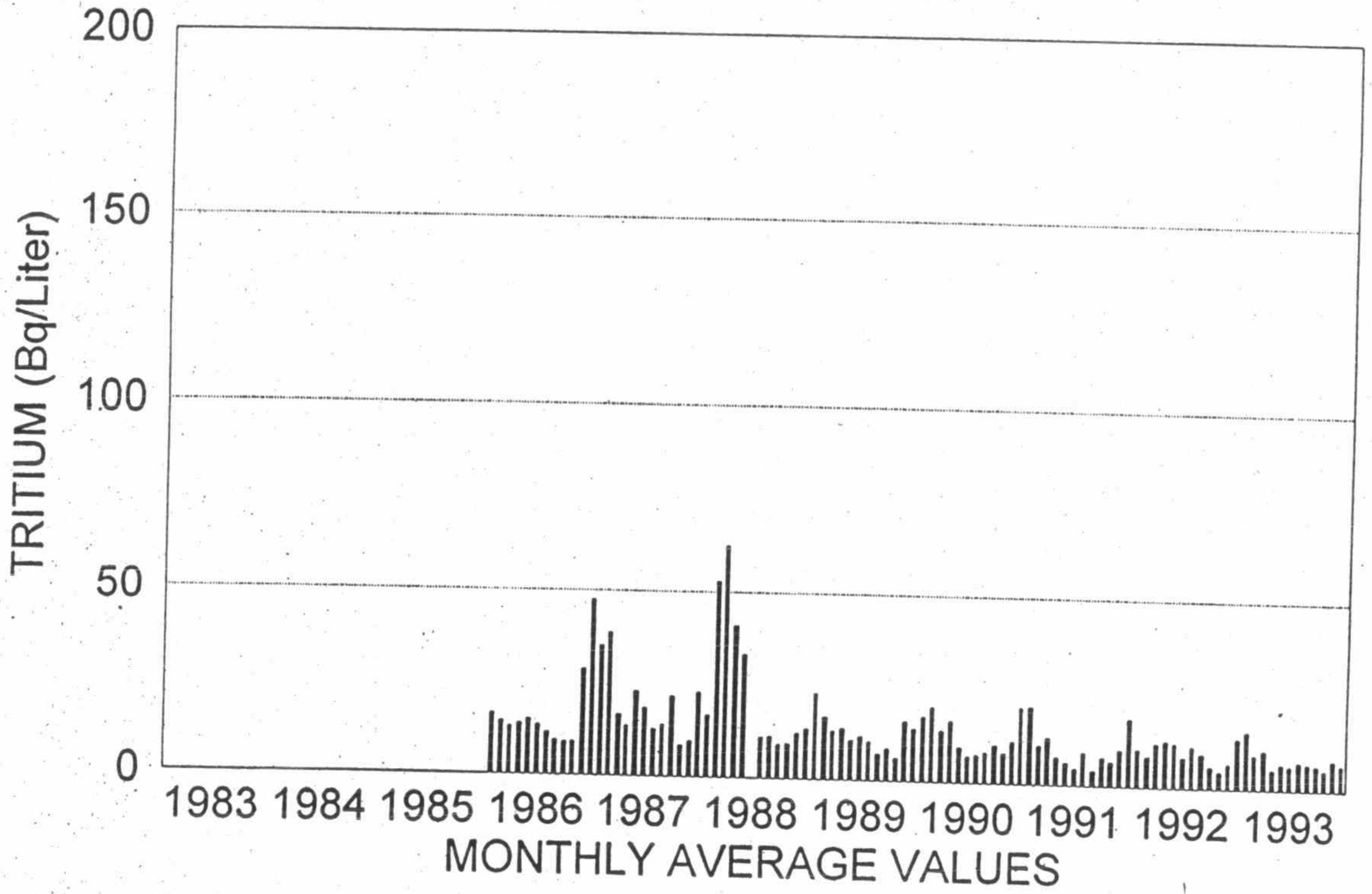
DRINKING WATER



NEWCASTLE WSP

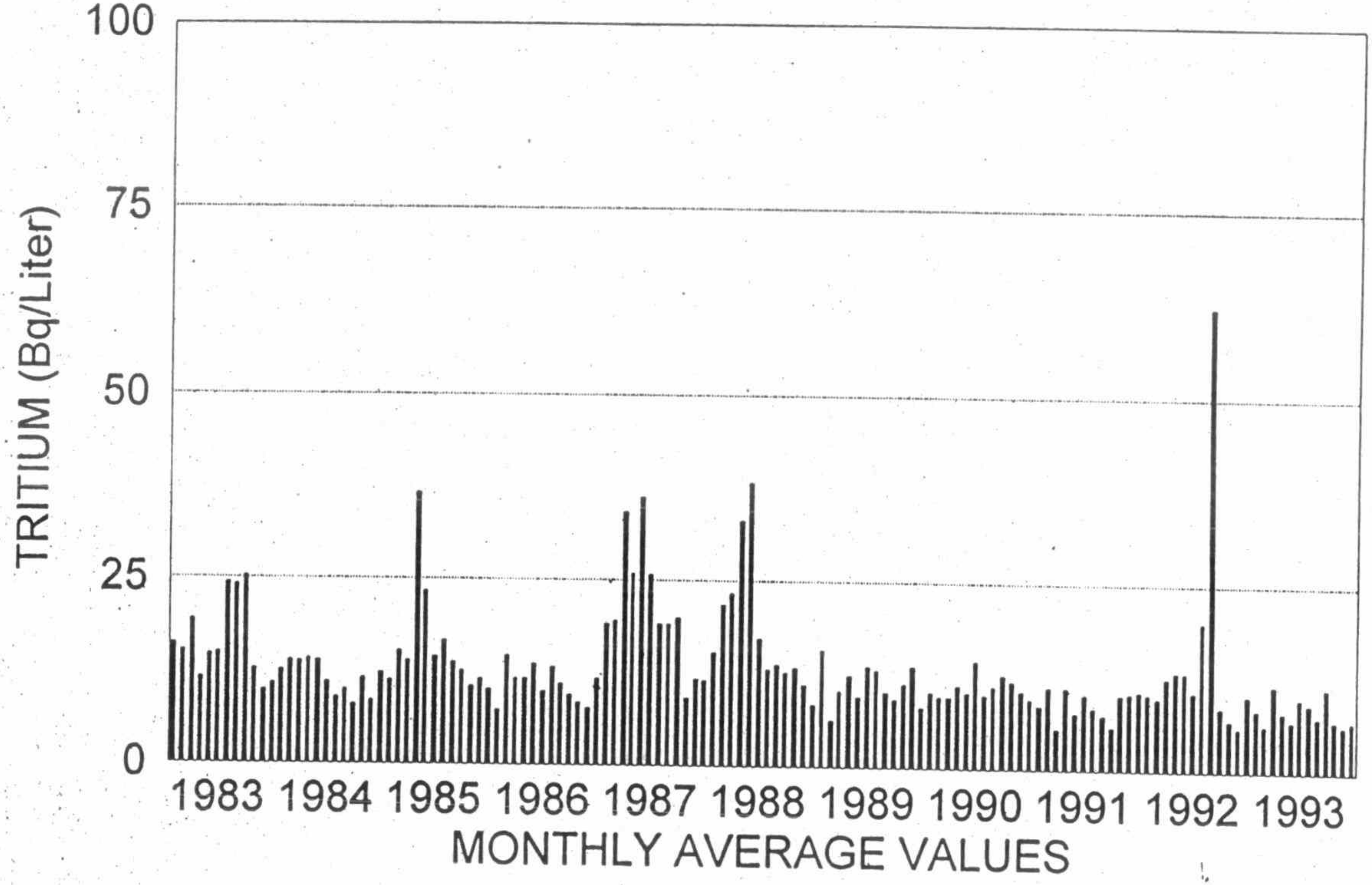
DRINKING WATER

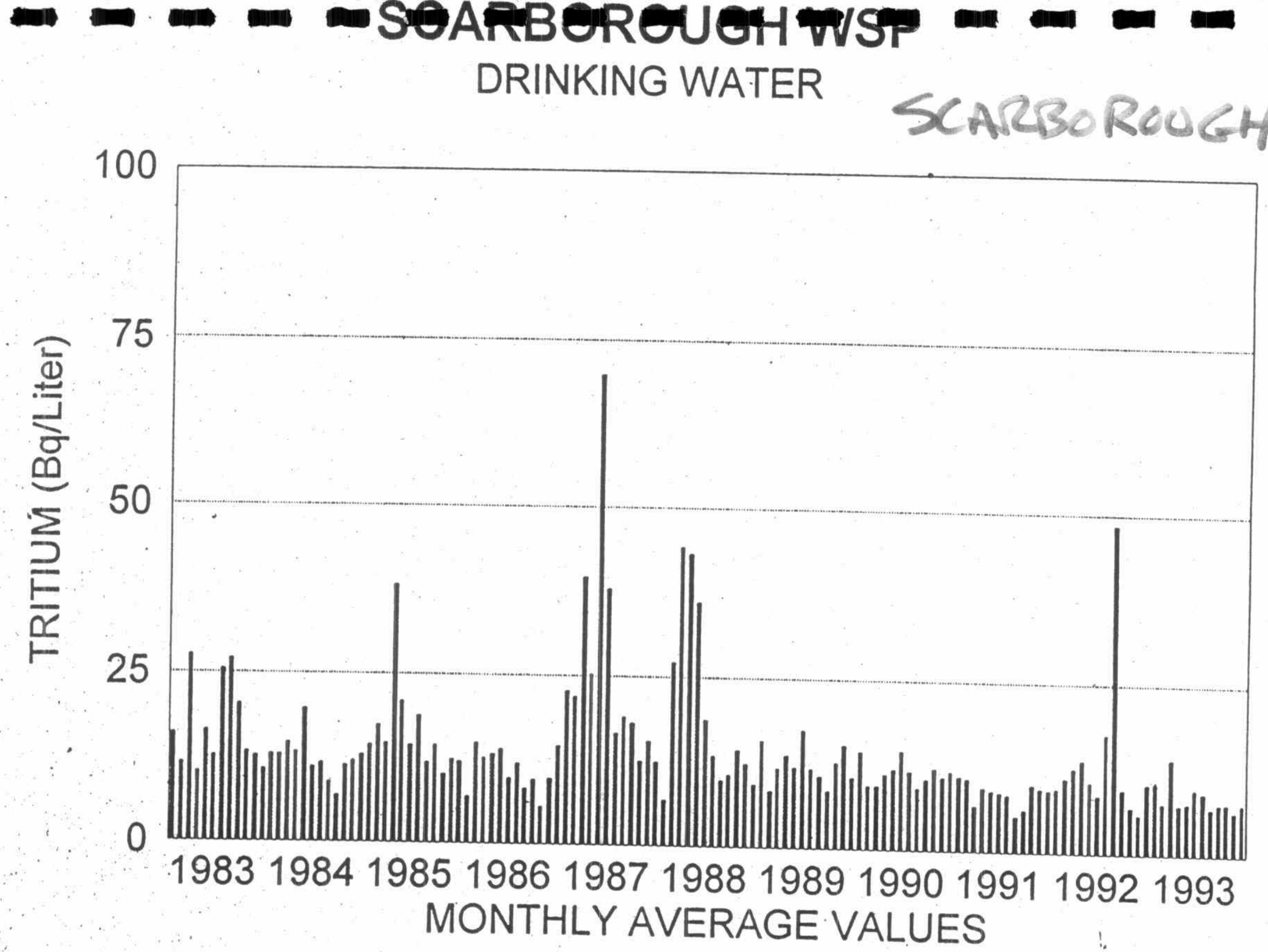
NEWCASTLE



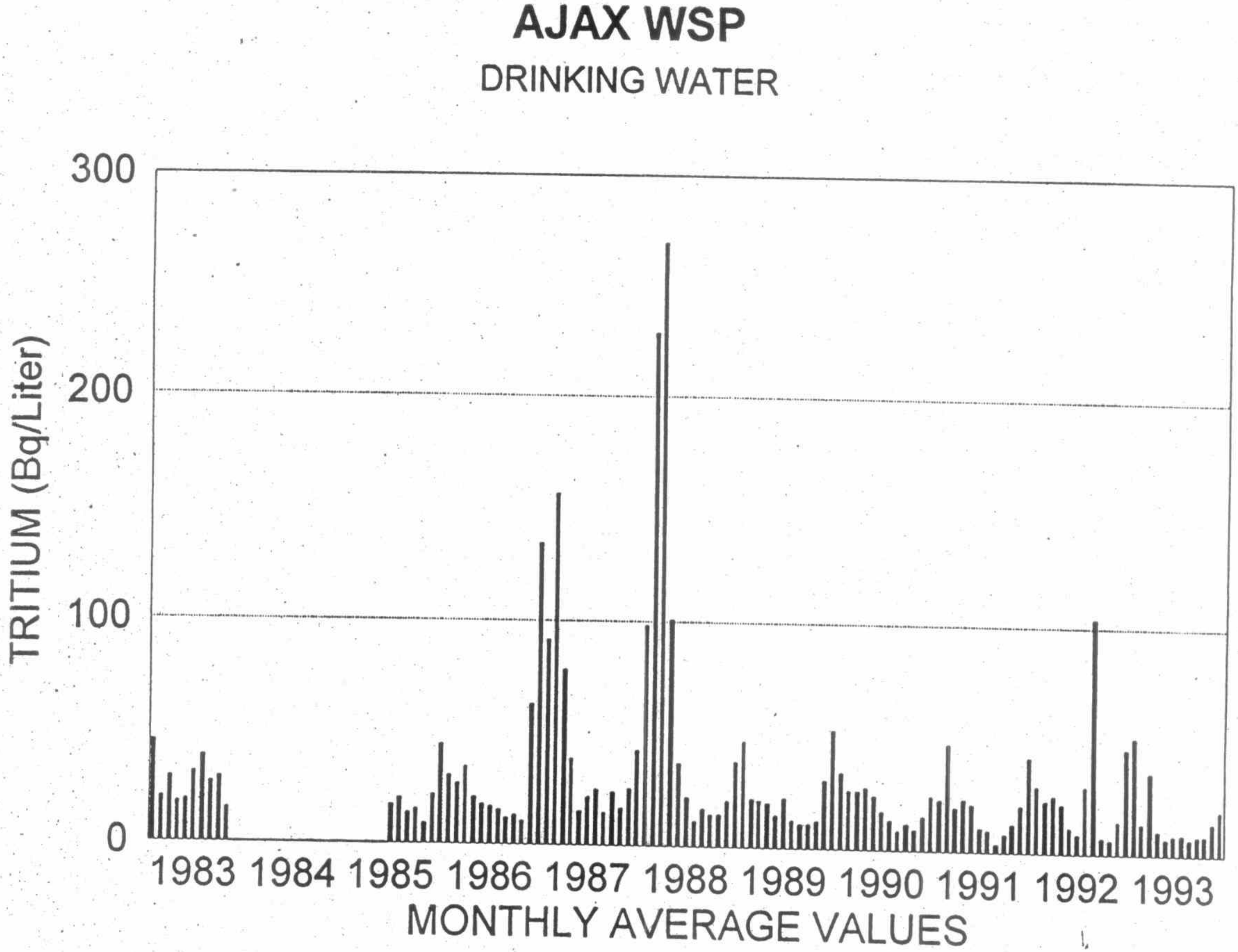
R.C. HARRIS WSP (TORONTO)

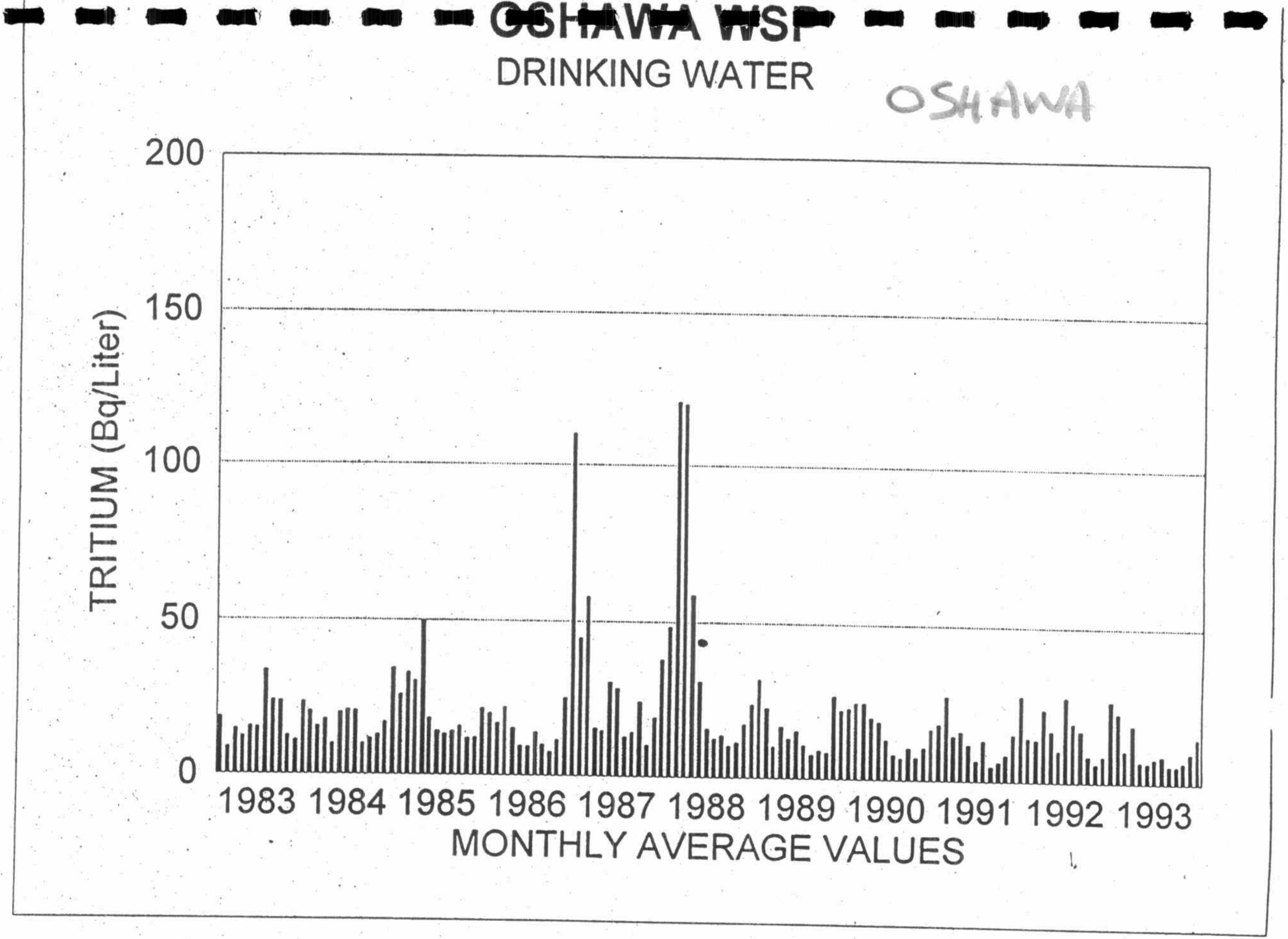
DRINKING WATER



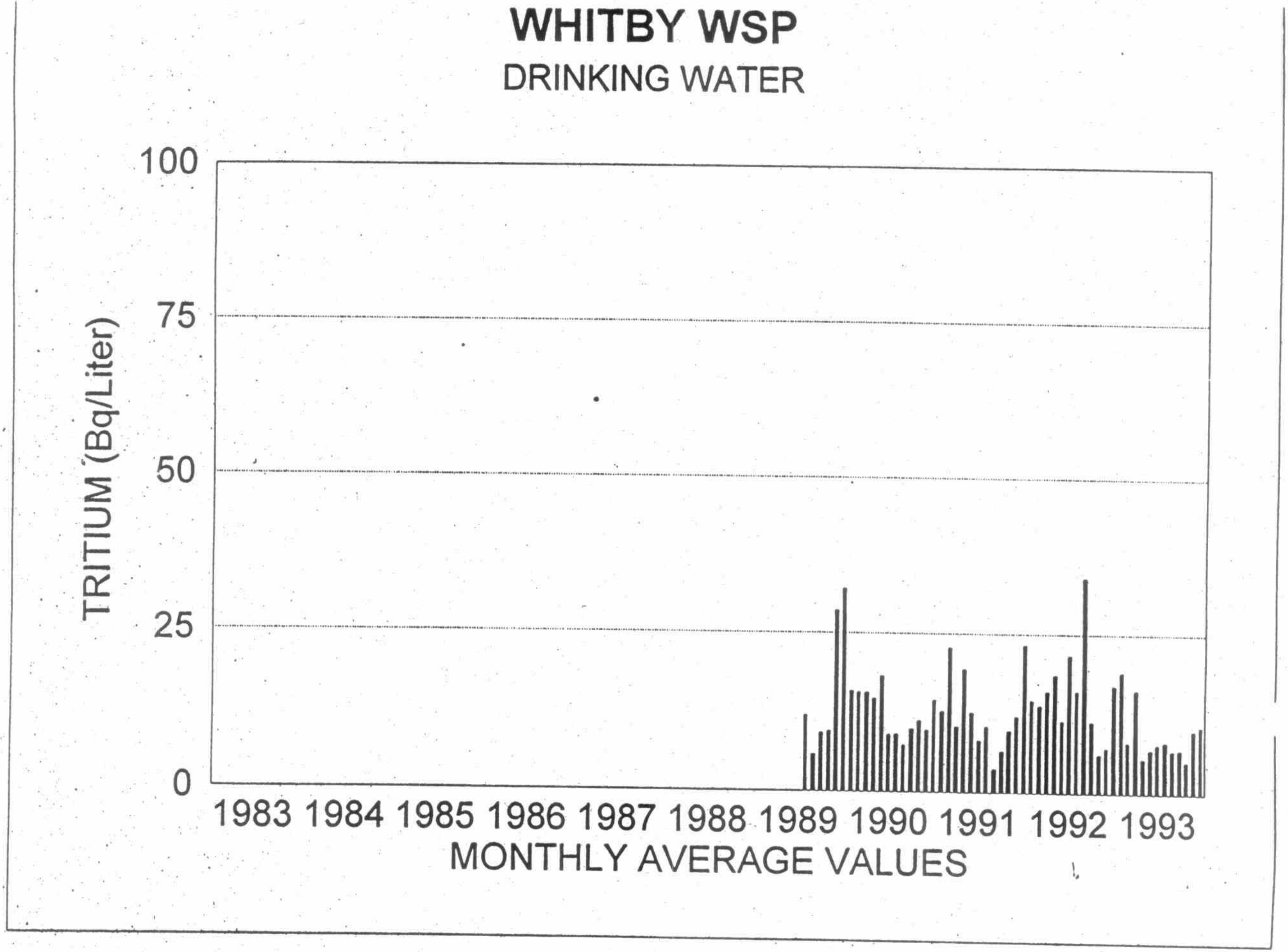


SCARBOROUGH


AJAX WSP
DRINKING WATER
TRITIUM (Bq/Liter)
300
200
100
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
MONTHLY AVERAGE VALUES


OSHAWA WSP
DRINKING WATER
TRITIUM (Bq/Liter)
200
150
100
50
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
MONTHLY AVERAGE VALUES

OSHAWA

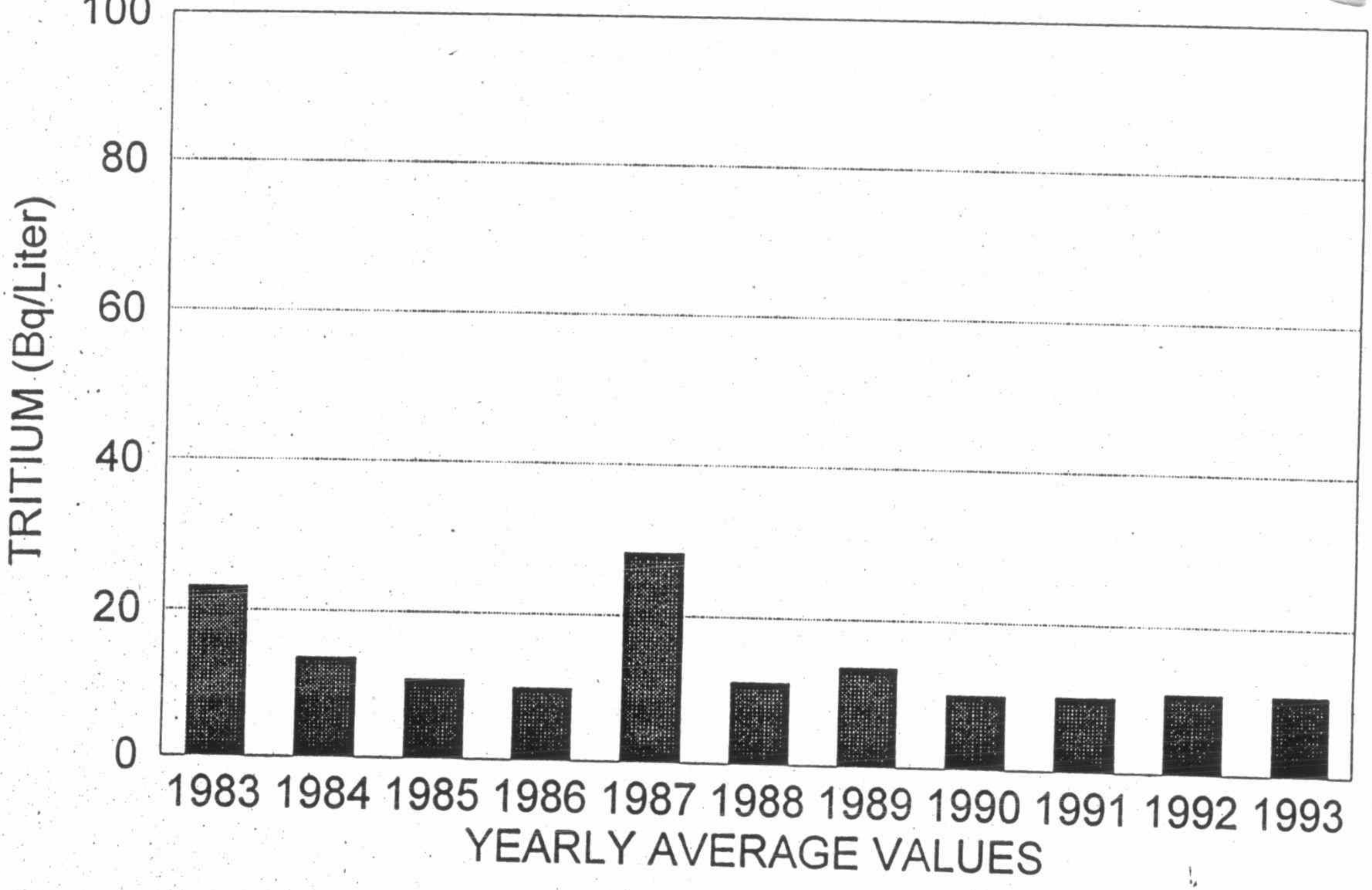

WHITBY WSP
DRINKING WATER
TRITIUM (Bq/Liter)
100
75
50
25
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
MONTHLY AVERAGE VALUES

B20

KINCARDINE WSP

DRINKING WATER

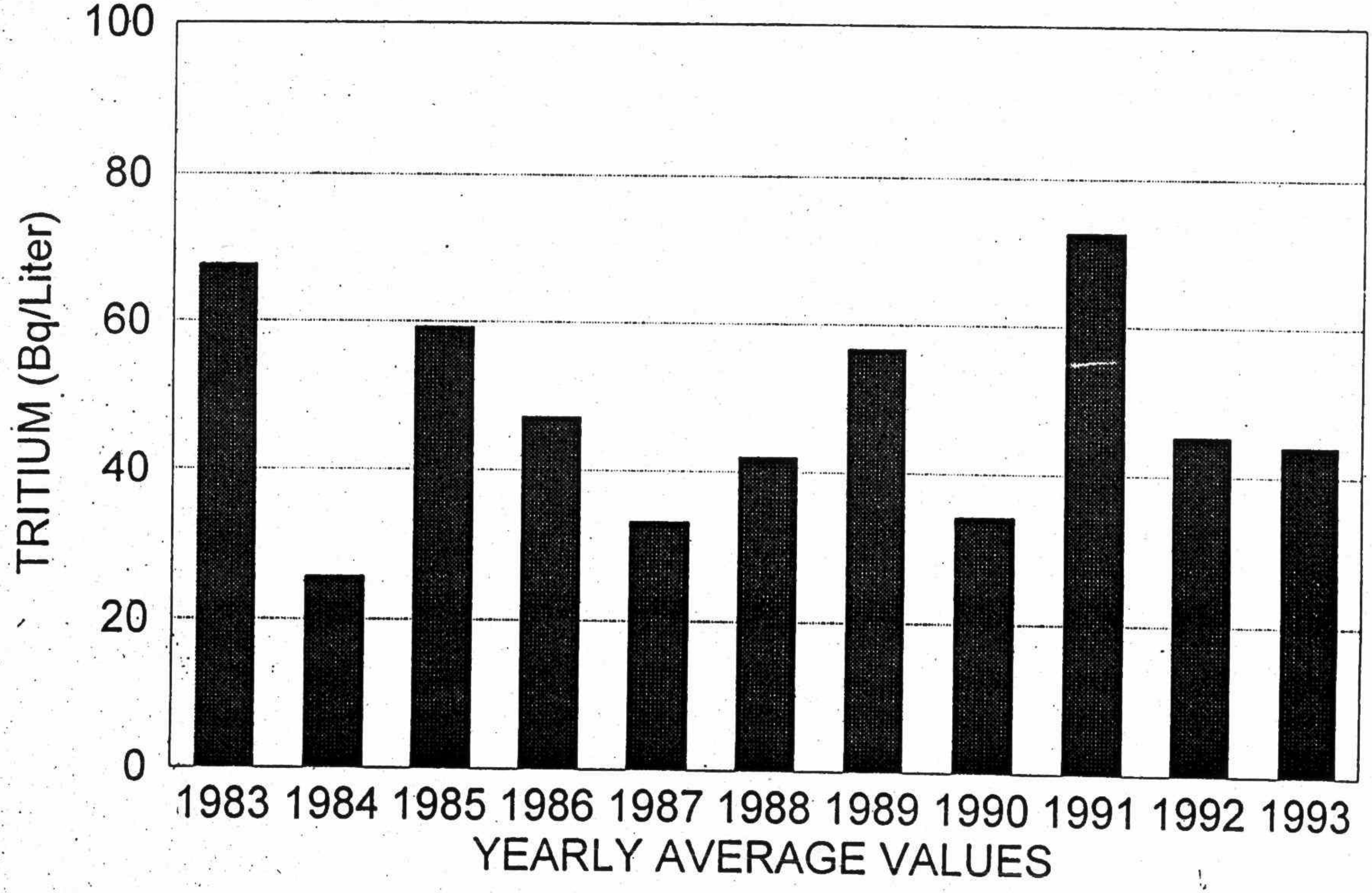
KINCARDINE



B21

PT. ELGIN WSP

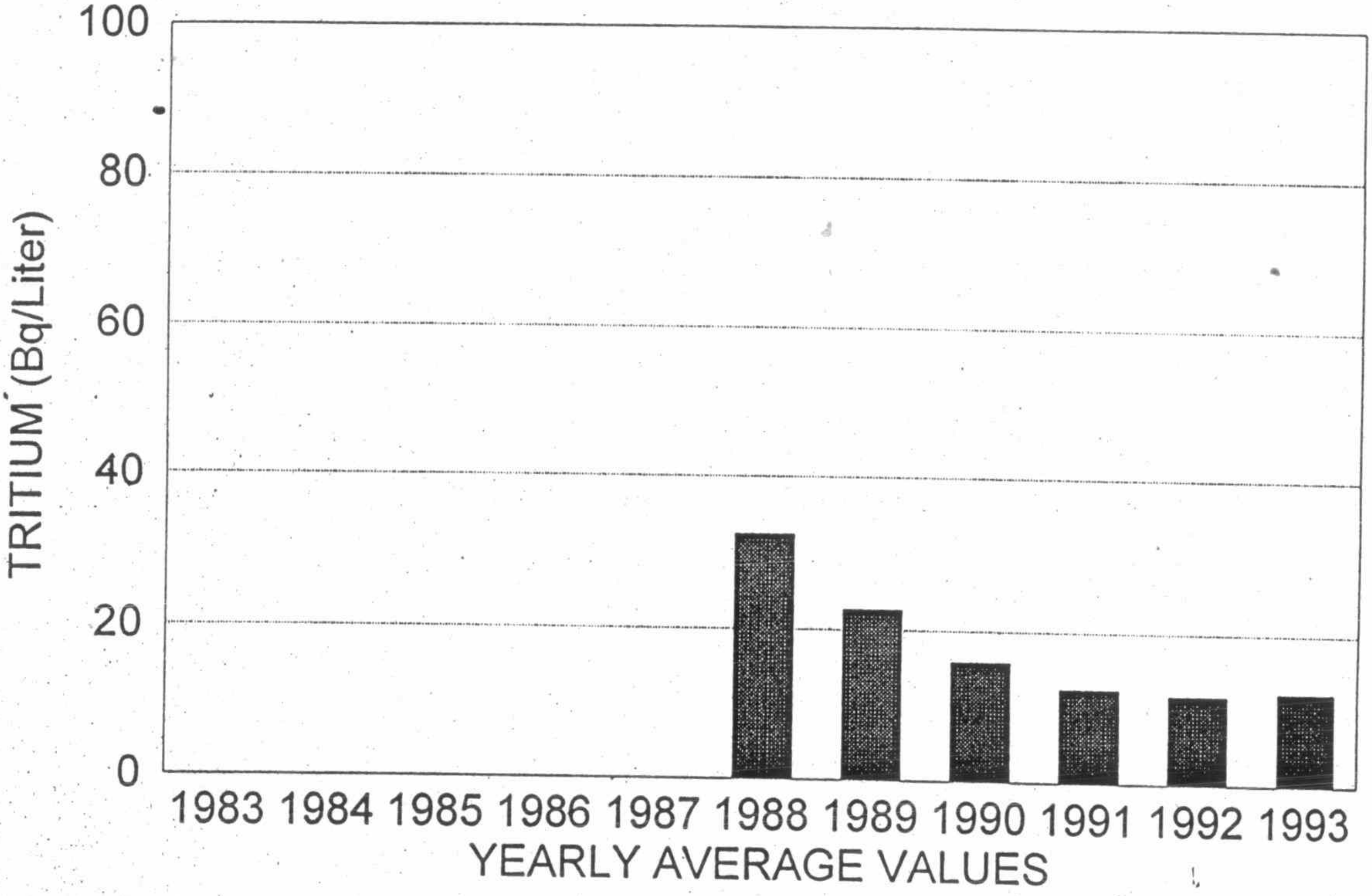
DRINKING WATER



~~ST. MARY'S CEMENT PLANT~~

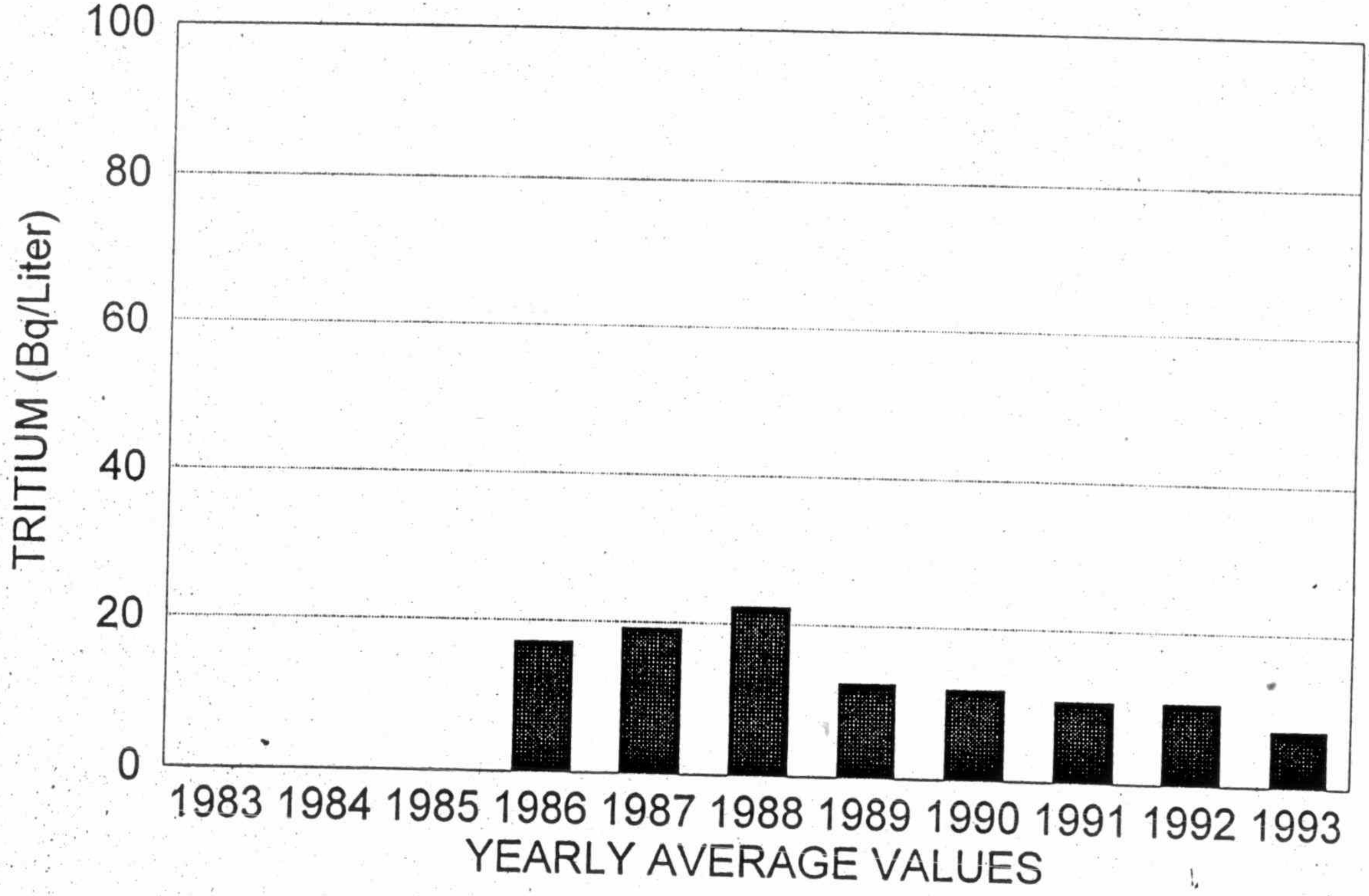
DRINKING WATER

ST. MARY'S CEMENT



BOWMANVILLE WSP

DRINKING WATER

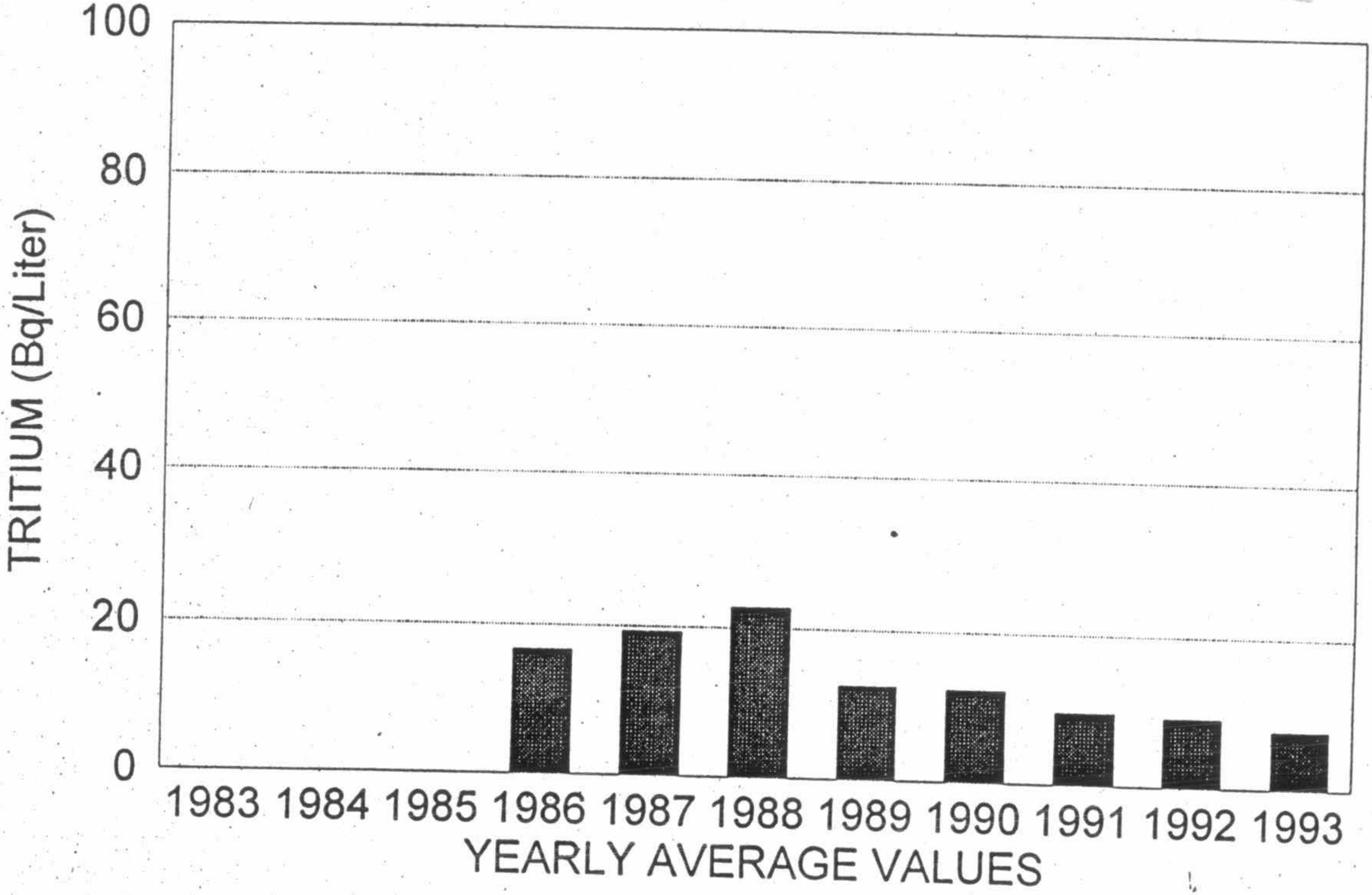


B24

NEWCASTLE WSP

DRINKING WATER

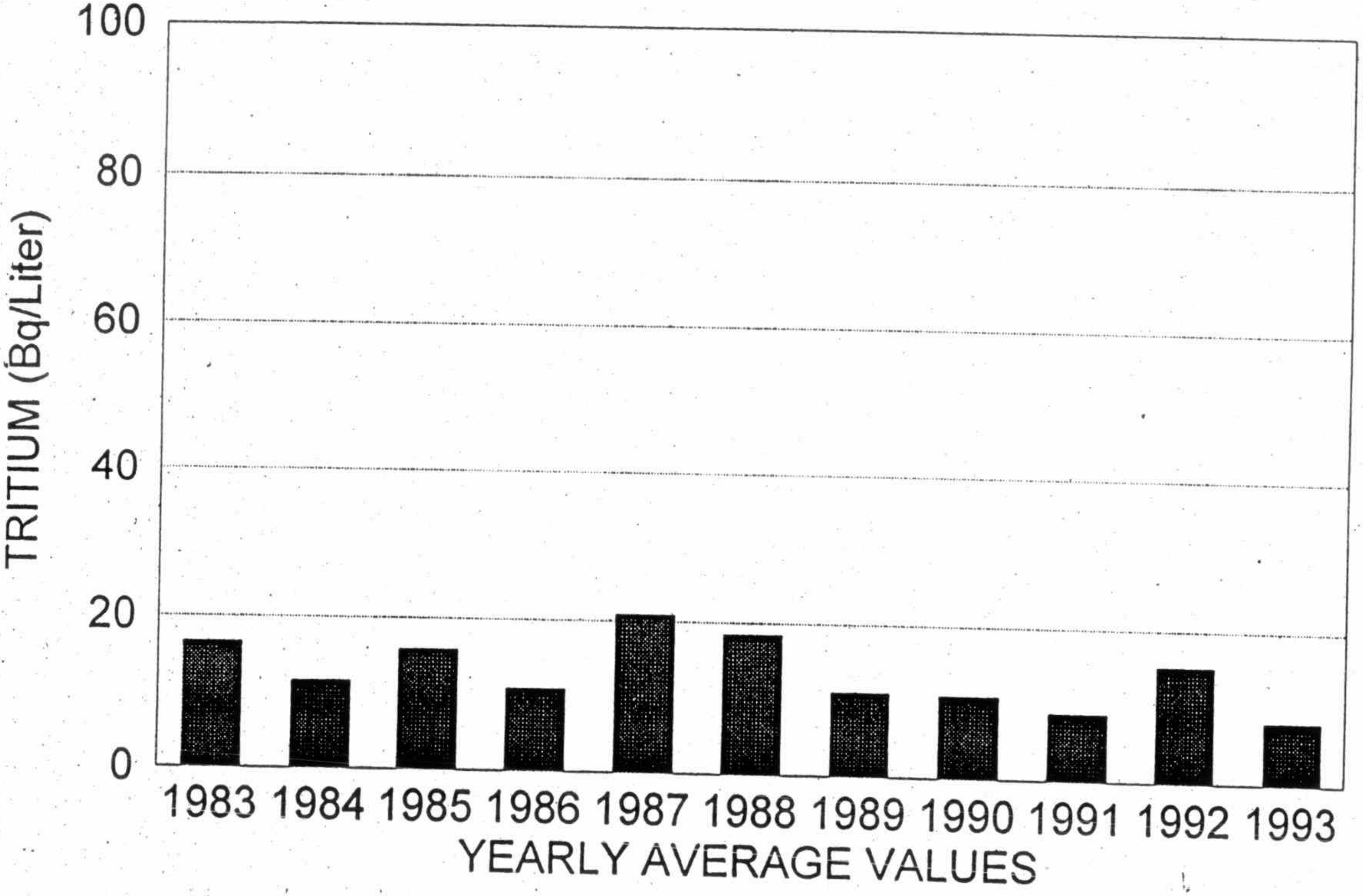
NEWCASTLE



B25

R.C. HARRIS WSP

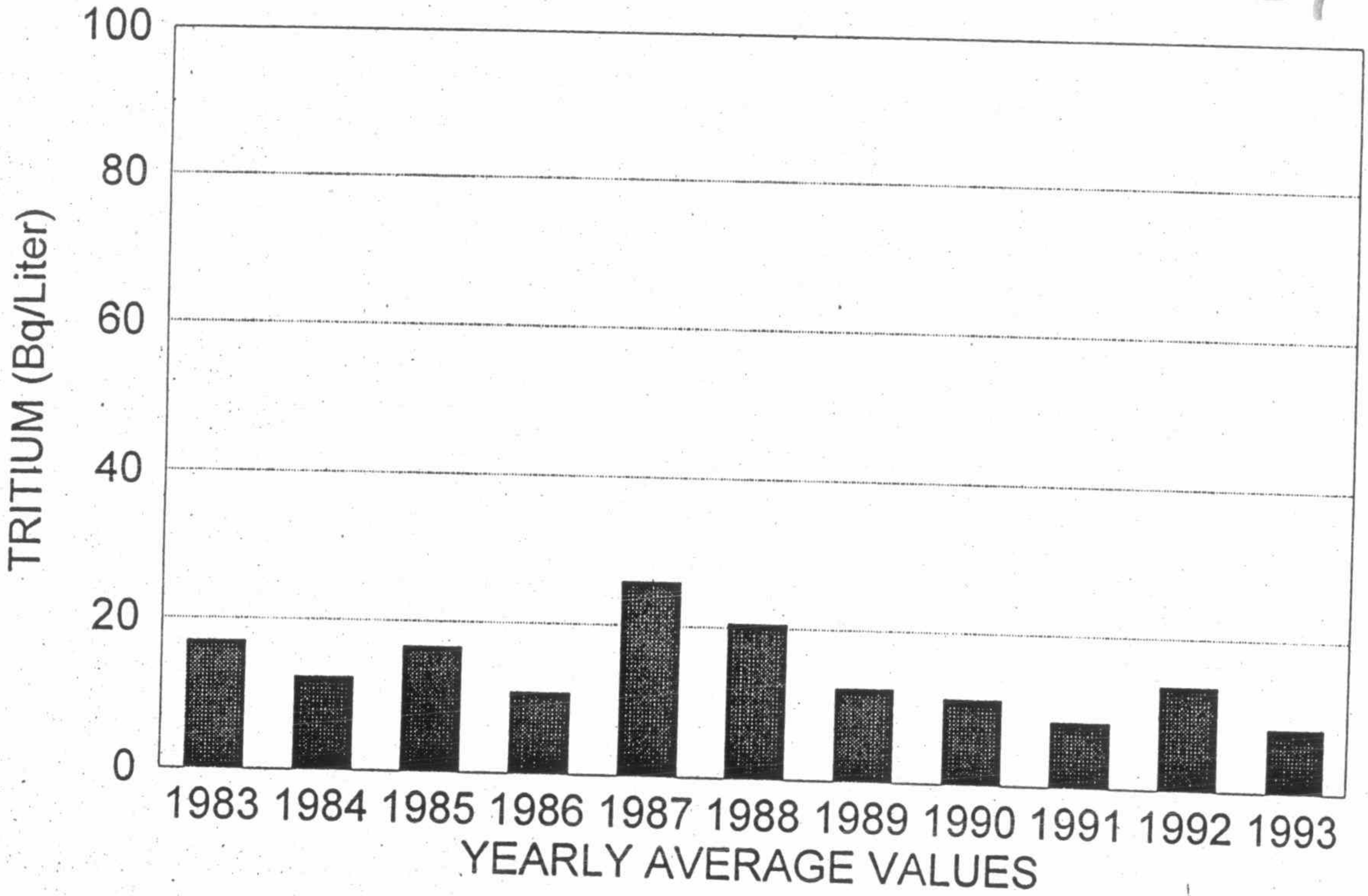
DRINKING WATER



~~SCARBOROUGH WSP~~

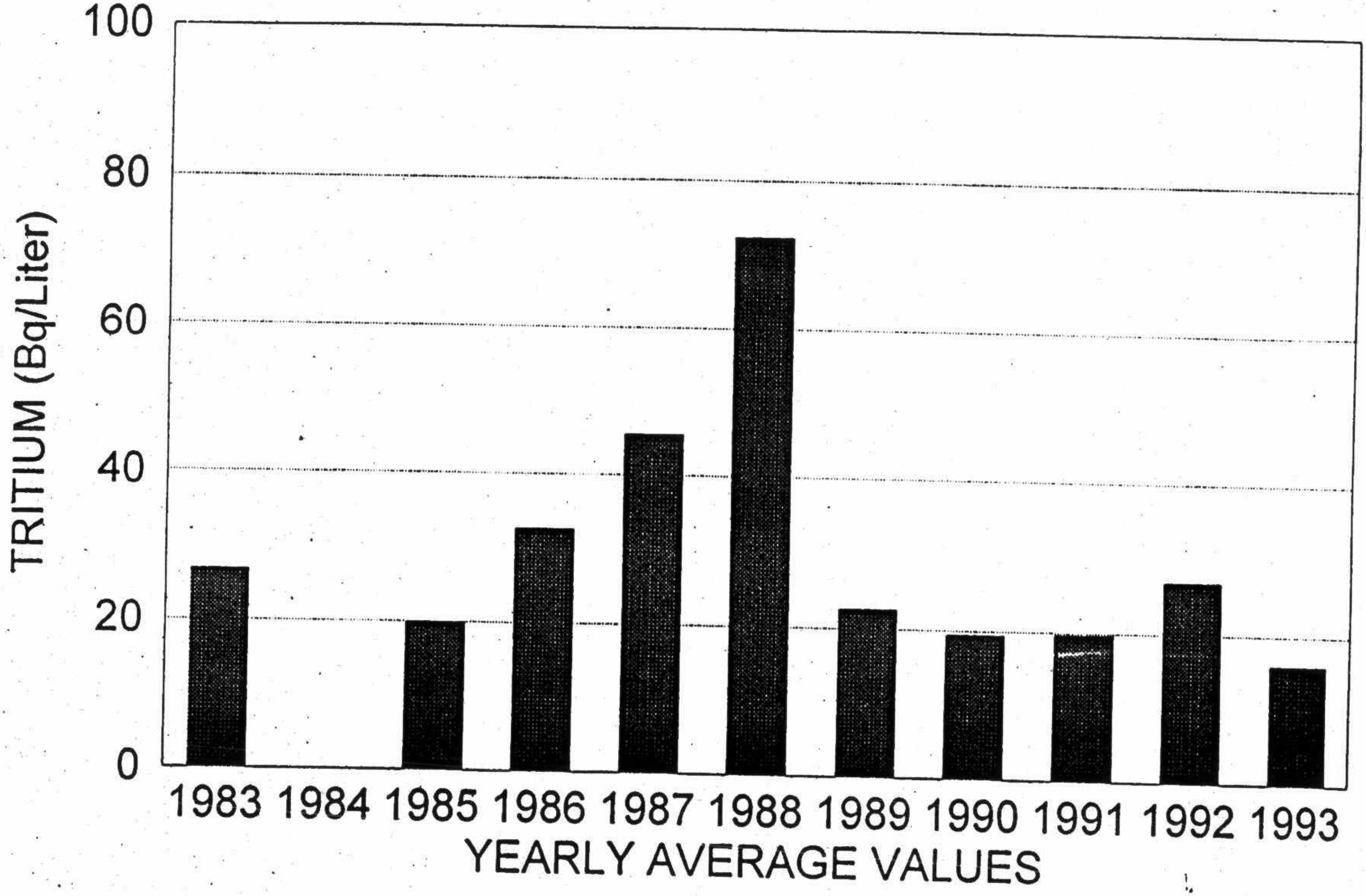
DRINKING WATER

SCARBOROUGH



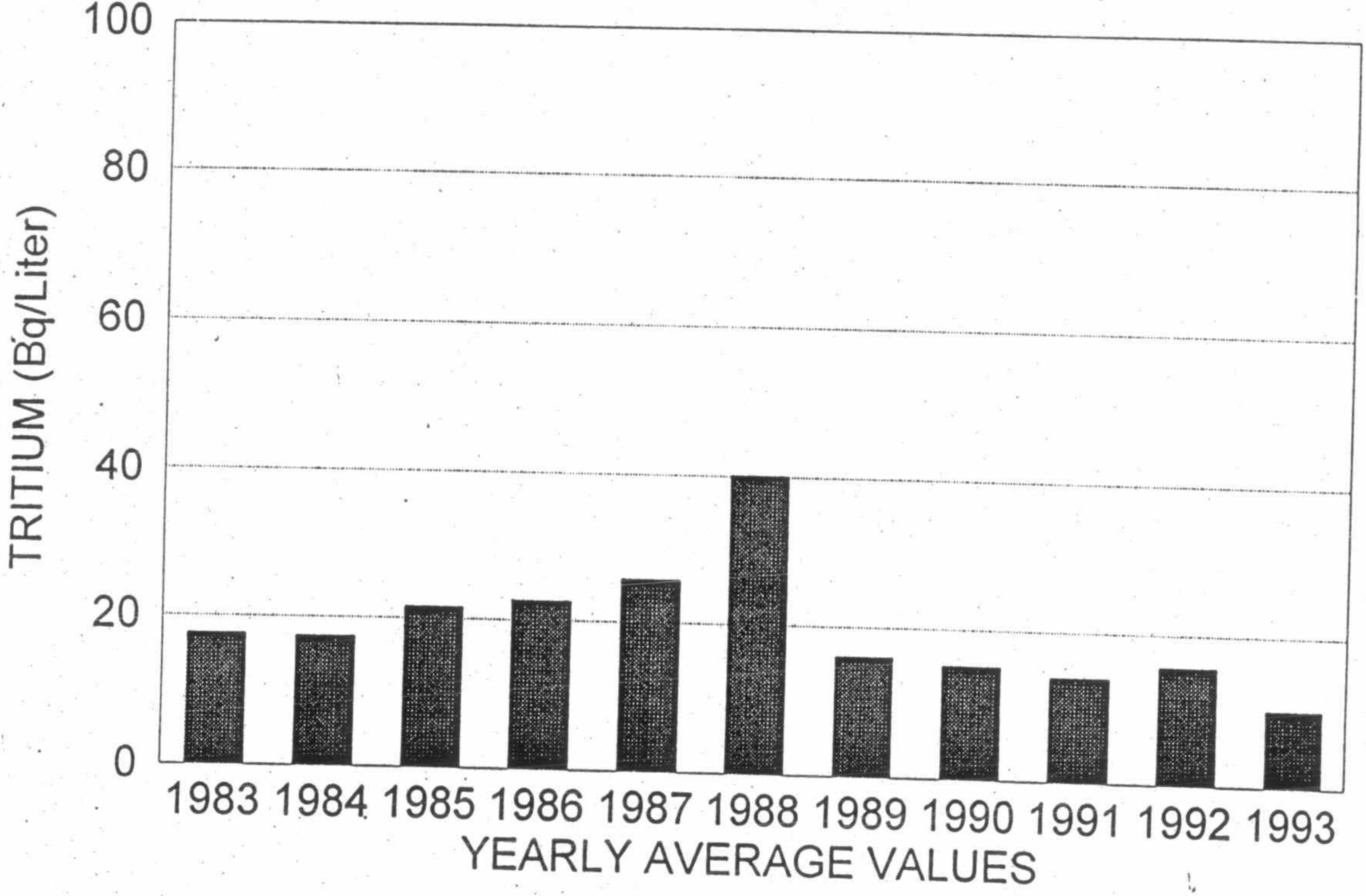
AJAX WSP

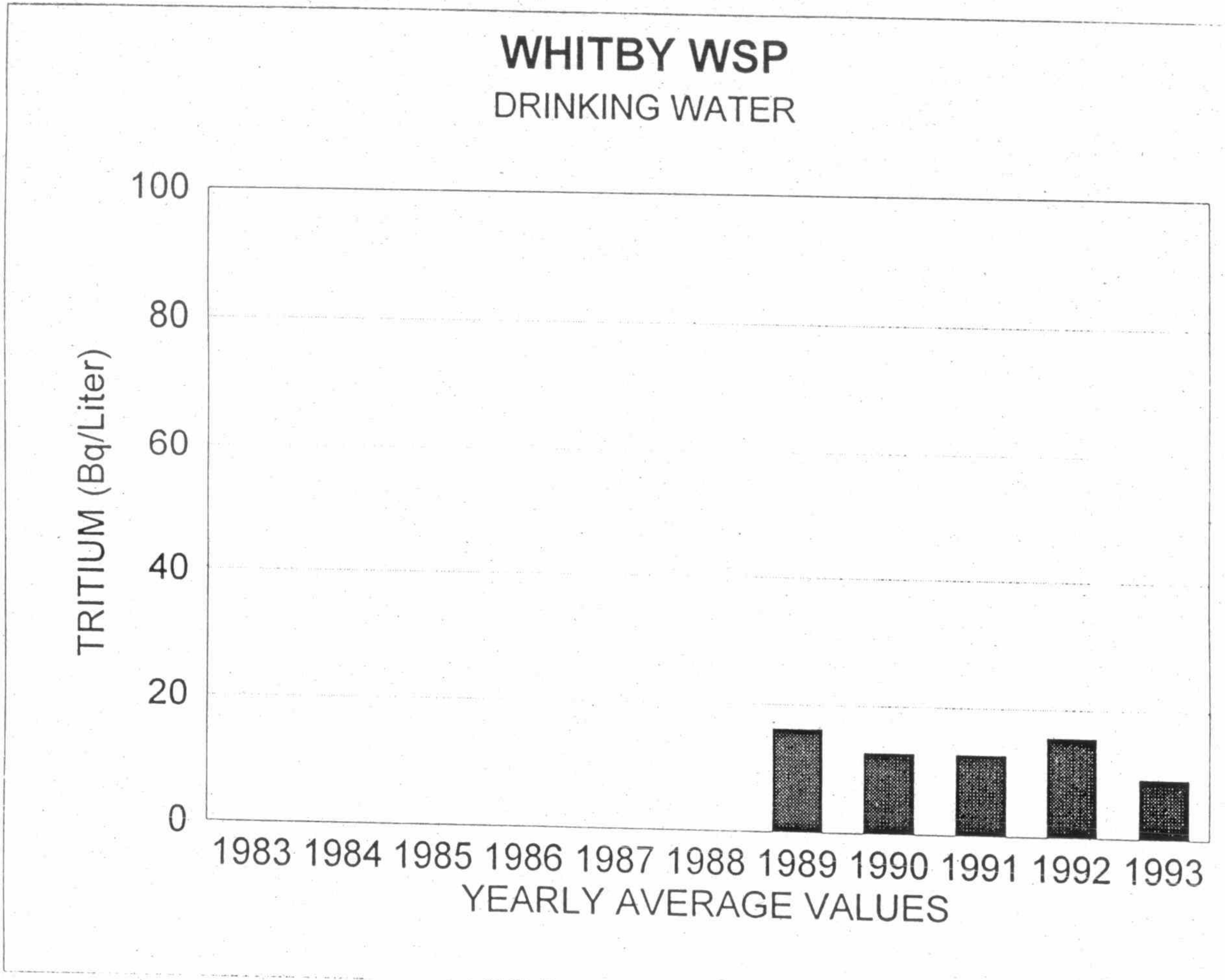
DRINKING WATER



OSHAWA WSP
DRINKING WATER

OSHAWA





WHITBY WSP

DRINKING WATER

APPENDIX C

Description of Current and Feasible Technologies to Reduce Tritium Releases

ATTACHMENT 1

Supplementary Submission to the Ministry of Environment and Energy on the Potential Impact of Reducing the Ontario Drinking Water Objective for Tritium

1.0 Introduction

This supplementary submission is in response to the ministry's (MOEE) request for cost information on existing measures and programs to reduce tritium emissions which were mentioned in our previous submission of August 26, 1994.

The programs to reduce tritium emissions which arise from equipment failures in the steam generators and moderator heat exchangers are outlined and costed below. Also included is a description of existing systems which reduce tritium emissions by collecting, processing and reusing heavy water/tritium that leaks within the plant.

The work described above is being performed for many reasons, including improving steam generator reliability and safety, not just to reduce tritium emissions to the environment. However, the end result of all these programs will be to reduce tritium emissions.

2.0 Steam Generator Performance Improvement Programs

Bruce NGS-A (Units 1 to 4):

The program includes: steam generator refurbishment, tube inspection/plugging, chemical cleaning and water lancing of steam generators, improvements in chemical control, and modifications to the balance of plant such as condenser retubing, feedwater heater replacement and a new station water treatment plant. Work has been ongoing since 1991 and is about 75% complete.

The total cost of this program is 194 M$ in capital expenses plus an estimated 1.3 M$/yr for operation and maintenance (inspection and chemical control).

The replacement energy which was provided for the additional 620 days of reactor outage attributable to steam generator work to date is estimated at 155 M$.

Pickering NGS (Units 1 to 8):

The steam generator performance improvement program includes: steam generator tube inspection/plugging and tube sleeving development, chemical cleaning and water lancing, decontamination, waste processing, strategic support, condenser and feedwater heater replacement and a full flow condensate filtration system.

The total projected cost for this program from 1994 to 1998 is 392 M$. Amounts spent in 1992 and 1993 total 62 M$. The estimated replacement energy cost for 612 maintenance outage days to date is 153 M$.

Bruce NGS-B and DNGS:

For each of these stations, operating and maintenance costs are in the range of 10 M$/yr, including steam generator inspection, cleaning and chemical control improvements.

3.0 Moderator Heat Exchanger Improvement Programs

The major cost in this area is incurred by moderator heat exchanger replacement programs currently underway at Pickering NGS-B and Bruce NGS-A. The cost of replacement is 16.5 M$ for Pickering NGS-B and 34 M$ for Bruce NGS-A. These replacements take place within a planned outage, so no additional energy replacement cost is incurred.

4.0 Combined Steam Generator and Moderator Heat Exchanger Program Costs

Total cost of ongoing programs to the end of 1998:

194 M$ + (1.3 M$/yr * 5 yr) + 34 M$ (Bruce NGS-A) +
392 M$ + 62 M$ + 16.5 M$ (Pickering NGS) +
(10 M$/yr * 5 yr) (Bruce NGS-B) +
(10 M$/yr * 5 yr) (Darlington NGS) = 805 M$

Total cost of replacement energy to date due to steam generator problems = 155 M$ (Bruce NGS-A) + 153 M$ (Pickering NGS) = 308 M$. Replacement energy costs for future steam generator maintenance from the present to 1998 has not been included.

Total program and replacement energy costs = $1.13 billion.

5.0 Heavy Water and Tritium Recovery and Reuse

Heavy water containing tritium escapes from station systems in various locations. Where practical, it is collected either as a liquid or water vapour, condensed if necessary, cleaned up, upgraded to reactor grade purity and reused. This prevents much of the leaked tritium from becoming an emission to the environment.

Tritium from heavy water inventories at all our nuclear stations is removed in our Tritium Removal Facility at Darlington NGS and stored in an immobilized form.

A description of the systems mentioned is given below.

Heavy Water (D2O) Cleanup

The heavy water cleanup system collects leakage and spills of D2O from the moderator and heat transport systems. The cleanup system removes any impurities such as organics and/or corrosion products found in D2O. It consists of an oil/water separator, charcoal filters and ion exchange columns containing mixed bed ion exchange resins. An on-line ion exchanger is also provided for the moderator system.

Heavy Water (D2O) Vapour Recovery

The vapour recovery system uses dryers to trap any D2O found in the atmosphere of the reactor vaults and other areas where high concentrations of D2O may occur before it can be discharged to the environment via the ventilation exhaust. The dryers consist of molecular sieve beds, heaters, a condenser, a blower and controls. Vapour trapped on the molecular sieve is released by heating and recaptured in the condenser. The vapour recovery system in each station consists of approximately 30 dryers.

Heavy Water (D2O) Upgrader

The upgrader plant removes any unwanted light water found in the D2O which was collected from leakage. It upgrades D2O to its original high isotope concentration for reuse in the reactors. This cuts down on D2O waste and reduces tritium emissions.

Tritium Removal Facility (TRF)

The TRF is designed to reduce the levels of tritium that build up over time in the D2O inventories of CANDU reactors. The removal of tritium from heavy water in the TRF reduces the average concentration of tritium in reactor systems, which in turn results in lower tritium emissions when any heavy water escapes to the environment.

The TRF process includes tritium extraction, tritium immobilization/storage, and tritium cleanup.

The tritium extraction consists of a feed and product storage system, feed treatment system, vapour recovery phase catalytic exchange, dryer unit and cryogenic distillation columns.

The tritium immobilization/Storage section consists of glove boxes, uranium beds, heaters, assay tanks, vacuum/transfer pumps, process loops, tritium analyzer/leak detectors, airlocks and immobilized containers.

The cleanup is made up of molecular sieve beds, hydrogen isotopes recombiner, heaters, condenser, blowers and controls.

A summary of the capital and operating costs for the above systems is found in Table 1. The total equipment cost is about 600 M$ and the operating/maintenance costs are about 97 M$/yr.

Table C.1
HEAVY WATER AND TRITIUM EMISSION REDUCTION COSTS

STATIONS	HEAVY WATER SYSTEMS	EQUIPMENT CAPITAL INSTALLATION COST[1] ($)	OPERATING COST[1] ($/ANNUM)
Bruce Nuclear Generating Station - A	D_20 Upgrader System[2]	50,000,000	5,000,000
	D_20 Vapour Recovery System	36,000,000	500,000
	D_20 Clean-up System	3,000,000	433,000
	TOTAL	89,000,000	5,933,000
Bruce Nuclear Generating Station - B	D_20 Upgrader System[2]	50,000,000	5,000,000
	D_20 Vapour Recovery System	36,000,000	500,000
	D_20 Clean-up System	3,000,000	433,000
	TOTAL	89,000,000	5,933,000
Pickering Nuclear Generating Station - A	D_20 Upgrader System[2]	50,000,000	5,000,000
	D_20 Vapour Recovery System	36,000,000	500,000
	D_20 Clean-up System	3,000,000	433,000
	TOTAL	89,000,000	5,933,000
Pickering Nuclear Generating Station - B	D_20 Upgrader System[2]	50,000,000	5,000,000
	D_20 Vapour Recovery System	36,000,000	500,000
	D_20 Clean-up System	3,000,000	433,000
	TOTAL	89,000,000	5,933,000
Darlington Nuclear Generating Station	D_20 Upgrader System[2]	33,000,000	32,000,000
	Tritium Removal System[2]	180,000,000	40,000,000
	D_20 Vapour Recovery System	36,000,000	500,000
	D_20 Clean-up System	3,000,000	433,000
	TOTAL	252,000,000	72,933,000
	GRAND TOTAL	608,000,000	96,665,000

[1] The operating cost includes interest charges, consumable and labour costs.

[2] The cost of building that houses the equipment is also included.

SOURCE: Ontario Hydro Supplementary Submission Ref #11.

ATTACHMENT 2

Supplementary Submission to the Ministry of Environment and Energy on the Potential Impact of Reducing the Ontario Drinking Water Objective for Tritium

1.0 Introduction

This supplementary submission is in response to the ministry's (MOEE) request for some more detail and cost information on one of the impact issues raised in our submission of August 26, 1994. The issue is the impact on other radionuclide emissions from Ontario Hydro nuclear generating plants if the MOEE were to adopt the Advisory Committee on Environmental Standards (ACES) recommendations for an Ontario Drinking Water Objective (ODWO) for tritium.

In our August 26 submission, we stated that if the MOEE adopted the ACES recommendations and modified them a bit to allow the ODWO to be applied on an average annual basis, it would appear as if there would be very little impact on Ontario Hydro. However, we argued that such an action would indeed have a very significant impact on us. Adopting the levels recommended by ACES on an average annual basis would amount to the MOEE adopting a new methodology for regulating radionuclides. ACES has proposed that guidelines for each radionuclide in each medium separately be based on a very low acceptable risk level of between 1 to 5 in a million. If the ACES recommendations were accepted then this methodology and risk basis would have to be applied to other radionuclides in order to maintain a consistent rationale for the protection of public health. We have applied this methodology to other radionuclides in other media and conclude that we would have to reduce significantly some of the other radionuclide emissions. This submission outlines our analysis in some more detail and goes on to briefly address the measures could be taken to make the corresponding emission reductions and their related costs.

2.0 Emission Reduction Factors Required for Risk Levels of 1E-6 to 5E-6

The lifetime risk of 5E-6 corresponds to an annual radiation dose of 1.43 uSv/yr over a period of 70 years. The 1 E-6 risk factor corresponds to an annual dose of 0.29 uSv/yr over 70 years. These doses are based on the International Commission on Radiological Protection (ICRP 1990) recommended risk conversion factor of 5E-2/Sv (annual dose), and is the same conversion factor used in the ACES report.

The doses corresponding to the 1E-6 and 5E-6 risk levels were compared to the estimated actual radiation doses received by members of populations that live around Ontario Hydro nuclear station sites. The estimates are based on our environmental monitoring program results for 1993 (OH 1994). Tables 1 to 6 inclusive are reproduced from the 1993 annual dose summary report (OH 1994). They show the estimated radiation dose to the critical group (most affected population) for an infant (Infant "A" and Infant "B") and an adult.

Infant "A" is one who drinks fresh local milk from local sources, while Infant "B" is one who drinks powdered formula reconstituted with tap water. Tables 1 to 5 address individual pathways, while Table 6 is a summary for each radionuclide group where doses from all pathways are combined (multiple pathway). Table 7 shows the reduction factors required if the doses resulting from emissions (i.e. from Tables 1 - 6) had to be reduced to 1.43 uSV/yr or 0.29 uSv/yr (i.e. the levels corresponding to lifetime risk factors of 5E-6 and 1E-6 respectively). This is presented for each of the various radionuclides and each exposure pathway. The maximum of the 3 doses for Infant "A", Infant "B" or Adult was chosen in each case. Table 8 summarizes Table 7 and also includes multiple pathway reduction factors. Table 8 is taken from our August 26 submission to the MOEE (where it appeared as Table 11). Note that results for BNPD (Bruce Nuclear Power Development) are for the effects of emissions from the whole site, and can not be broken out further for the Bruce A or Bruce B generating stations.

The doses in Tables 1-6 for carbon-14 and for tritium in water do not include background, while the rest do.

There was insufficient time to extend this analysis to other years.

3.0 Possible Measures to Achieve Emission Reduction Factors

The following analysis of possible emission reduction measures and their related cost estimates have been done in a very limited time frame as requested by the MOEE, and are necessarily very preliminary.

3.1 Tritium to Air Emissions

Our August 26 submission mentions the heavy water (and thus also tritium) management system and the various means taken to control heavy water (D_2O) losses and thus tritium within our plants. These consist in part of design features (e.g. bellows sealed valves), liquid D_2O collection systems, D_2O recovery systems (D_2O cleanup, D_2O upgraders)and re-use of the D_2O and the Tritium Removal Facility which reduces the concentration of tritium in the D_2O.

There are also means of recovering D_2O vapour from station air. The D_2O vapour recovery systems remove D_2O (and thus tritium) from air in parts of the reactor building and from other areas of the plant where there are significant amounts of D_2O. This reduces tritium emissions in the plants' ventilation exhaust. In the dryers, the D_2O is adsorbed on a molecular sieve dessicant bed and later recovered by regenerating the bed with heat, driving off the adsorbed water vapour and condensing it to liquid form. The recovered liquid is then sent to the D_2O upgraders for processing and re-use.

Even though elaborate, in-depth measures exist to prevent D_2O/tritium losses, there are still numerous minute leaks in systems containing D_2O which result in vapour phase D_2O (and tritium) escaping to station atmosphere and being emitted to the environment via ventilation exhaust. The sources are very small and numerous as a result of the large number of valves, fittings, instruments, pressurized systems, sampling ports, heat exchangers, equipment seals, etc. Any sizeable leak is normally detected and quickly repaired for reasons of worker safety, environmental protection and economics (D_2O losses are expensive).

The only method of keeping the numerous small sources of tritium from becoming emissions is to install large capacity dryers on the station ventilation exhaust systems and remove the tritium from this stream. In order to keep the collected tritium from becoming a liquid emission, the resulting collected light water contaminated with trace amounts of tritium would then have to be treated in a (hypothetical) vacuum distillation detritiation plant as described in section 4.1.1 of our August 26 submission.

The cost of drying all of a typical station's exhaust air streams where tritium may be emitted is estimated in Table 9 (example, Bruce NGS-A) at about 64 M$ capital costs and 0.9 M$/yr operating/maintenance costs. Thus, removing tritium from ventilation exhaust and also reducing airborne tritium emissions at all Ontario Hydro stations would cost about 250 million dollars capital and about 3.6 million dollars per year in ongoing operating and maintenance costs.

This estimate is based on a rough cost estimate of existing dryer systems for the Darlington plant, i.e. about 36 M$ to purchase and install equipment with a 112,000 cfm drying capacity plus about 0.5 M$/yr for operating/maintenance costs. The cost of adding more capacity to proposed vacuum distillation detritiation units (to treat captured tritium in dryers) was not estimated and is not included in the above total.

3.2 Noble Gas Emissions to Air

Noble gas emissions are produced from the activation of stable Argon (normally in air) to Argon-41, and from various fission products (Xenons, Kryptons) produced in the nuclear fuel. The Argon originates in trace impurities in the CO_2 annulus gas, trace impurities in the helium found in moderator cover gas, reactor zone control and bubbler systems, and from any inleakage of air to any of these systems. It has been estimated that Argon-41 is the most significant noble gas while the reactor is in normal operation (i.e. no significant fuel defects - fuel defects are pinhole leaks that develop in the metal sheath surrounding the uranium fuel while it is in the reactor and which permit fission product noble gases to escape into the heat transport D_2O).

Sources can be reduced by improving the fuel performance, i.e. improved fuel specifications, quality assurance and deployment of the fuel while inside the reactor. These factors are continually being monitored, analyzed and improvements are implemented. Ontario Hydro dedicates a large amount of resources to defect fuel bundle inspections, studies to develop improved fuel and operating procedures to minimize the development of fuel defects while the fuel is in service. Ontario Hydro works closely with Atomic Energy of Canada in this area.

Another method of source reduction is to quickly remove any fuel that develops a defect so that radioactive iodine and noble gas emissions are minimized. This is possible because of the CANDU reactor design which allows for on-power refuelling. Systems are in place in all of our stations that can detect the occurrence of fuel defects by radiation measurement, and to some extent, to help locate the defect fuel bundle within the hundreds of fuel channels in the reactor. Some improvements could be made to these detection/location systems. The Pickering system could be replaced by the better design used in the Bruce reactors at a ballpark cost of about 10 M$/reactor unit (120M$ total). There is no estimate on the amount of noble gas emissions reduction this might achieve.

A third measure is to treat the noble gases before they are emitted to the environment. As the noble gases are unreactive, the best treatment method is to delay them within the plant and allow these short half-life radionuclides to decay as much as possible before they are emitted. Systems are in place in each plant to accomplish such treatment (offgas management systems). However, they have never worked very well, and since they were not needed to keep noble gas emissions below one percent of the Atomic Energy Control Board's (AECB) licensed emission limits, improvements in this area were not a high priority. Darlington NGS is currently looking into developing improvements to its off-gas management system (OGMS). It should be noted that under normal operation, none of the OGMS's are capable of reducing the Argon-41 emissions because they were only designed for treating heat transport and fuel-related systems. As mentioned before, Argon-41 is the most significant noble gas during normal operation. There is no estimate at present for the potential cost of upgrading all OGMS's or for extending their design to capture Argon-41. There is also currently no estimate for the potential improvement in Noble Gas Emissions that would result.

3.3 Carbon-14 Emissions to Air

Before discussing carbon-14 sources, methods of emission reduction and potential costs, it must be stressed that even if we achieved the reductions required to reach a risk level of 5E-6 or 1E-6, the natural background level of carbon-14 (250 Bq/kg-C) which will be found in produce fish and milk is already higher than the concentrations you would need to achieve lifetime risk levels of 5E-6 or 1E-6. The levels of carbon-14 in water, fish, milk and produce which correspond to lifetime risk levels of 1E-6 and 5E-6 are given in Table 10. See also the note on carbon-14 at the end of Table 8.

Carbon-14 is produced mostly from a neutron reaction of oxygen-17 which is present in the D_2O. The largest production is in the moderator system where a large amount of D_2O is continually in the reactor neutron flux. A significant, but smaller amount is produced in the heat transport system where smaller amounts of D_2O are in the reactor neutron flux. Even smaller amounts are produced in the fuel itself and from the neutron activation of nitrogen impurities in the CO_2 annulus gas systems. The Pickering A plant used to have nitrogen filled annulus gas systems which produced large amounts of carbon-14, but these were all changed to CO_2 filled systems to eliminate this source of carbon-14 when these reactors were retubed.

It is estimated that most of the carbon-14 emissions originate from the moderator system. Carbon-14 in moderator water is captured on the moderator ion exchange resins and stored as radioactive waste. However, some of the carbon-14 comes out of solution and gaseous carbon-14 species (mostly CO_2) enter the helium moderator cover gas. This system has regular pressure relief venting and occasional purging which allows some gaseous carbon-14 to be emitted via the ventilation exhaust pathway. There is no in-station treatment for this emission pathway because actual measured emissions are well below one percent of the AECB licensed emission limits for carbon-14.

If carbon-14 emissions had to be reduced, they could be removed at the moderator cover gas system. Although this is not the only source it is most likely the largest, hence the choice of this location. Previous experience with carbon-14 scrubber prototypes (carbon oxidation and liquid caustic bubbler systems) at Ontario Hydro are the basis for a rough estimate of the cost of installing such devices on all reactor units. The estimated capital cost is about 21 M$. The actual reduction in emissions is not estimated but would likely be at least one-half.

3.4 Other Emissions

There was insufficient time to address other radionuclide emissions, e.g. particulate to air or water.

4.0 Conclusions

There is a large potential impact on Ontario Hydro if most of its radioactive emissions had to be reduced as a result of the MOEE adopting the ACES recommendation for the ODWO for tritium. The cost is roughly over 200 million dollars in capital plus around 3 M$/yr additional operating costs. We strongly believe adoption of ACES recommended methodology and lower acceptable risk levels at this time would influence the regulated levels of all radionuclide emissions to drop to the same levels. We also repeat that we see very little added benefit in adopting these risk levels, particularly when the resultant doses are compared with the radiation dose received from natural background sources.

REFERENCES

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OH 1994 Annual Summary and Assessment of Environmental Radiological Data for 1993, Report No. N-03419-940035-P OUO, J. LaMarre, April 29, 1994.

TABLE 1

Table 5.1.2.1b - Critical Group Doses from Noble Gas - 1993

Pathway	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (µSv)			Critical Group Dose (µSv)			Critical Group Dose (µSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Immersion in semi-infinite cloud	1.3	1.3	1.3	9.6	9.6	9.6	2.1	2.1	2.1

TABLE 2

Table 5.1.2.2b - Critical Group Doses from Tritium - 1993

Pathway	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (μSv)			Critical Group Dose (μSv)			Critical Group Dose (μSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Inhalation/skin absorption	1.2×10^{-1}	1.2×10^{-1}	2.4×10^{-1}	1.3	1.3	2.6	8.3×10^{-1}	8.3×10^{-1}	1.7
Ingestion (drinking water)	2.8×10^{-3}	3.2×10^{-2}	2.0×10^{-2}	1.5×10^{-2}	1.7×10^{-1}	1.0×10^{-1}	7.1×10^{-2}	8.2×10^{-1}	4.9×10^{-1}
Ingestion (milk)	1.9×10^{-1}	0	2.2×10^{-2}	0	0	0	3.1×10^{-1}	0	3.5×10^{-2}
Ingestion (Fruit & Vegt.)	9.3×10^{-2}	9.3×10^{-2}	7.8×10^{-2}	7.3×10^{-1}	7.3×10^{-1}	6.1×10^{-1}	9.0×10^{-1}	9.0×10^{-1}	7.5×10^{-1}
Ingestion (Fish)	2.7×10^{-4}	2.7×10^{-4}	9.1×10^{-4}	1.6×10^{-3}	1.6×10^{-3}	5.5×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	6.9×10^{-3}
Total	4.1×10^{-1}	2.4×10^{-1}	3.6×10^{-1}	2.0	2.2	3.3	2.1	2.6	3.0

TABLE 3

Table 5.1.2.3b - Critical Group Doses from ^{14}C in 1993

Pathway	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (μSv)			Critical Group Dose (μSv)			Critical Group Dose (μSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Ingestion (milk)	1.7 x 10^{-1}	0	1.8 x 10^{-2}	0	0	0	0	0	0
Ingestion (Fruit & Vegt.)	4.6 x 10^{-1}	4.6 x 10^{-1}	3.6 x 10^{-1}	3.2	3.2	2.5	1.2	1.2	9.8 x 10^{-1}
Ingestion (Fish)	5.0 x 10^{-3}	5.0 x 10^{-3}	1.6 x 10^{-2}	6.3 x 10^{-3}	6.3 x 10^{-3}	2.1 x 10^{-2}	2.0 x 10^{-2}	2.0 x 10^{-2}	6.6 x 10^{-2}
Total	6.3 x 10^{-1}	4.6 x 10^{-1}	3.9 x 10^{-1}	3.2	3.2	2.5	1.3	1.3	1.0

TABLE 4

Table 5.1.2.4b - Critical Group Doses from ^{131}I in 1993

Pathway	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (µSv)			Critical Group Dose (µSv)			Critical Group Dose (µSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Inhalation/skin absorption	3.4×10^{-5}	3.4×10^{-5}	2.4×10^{-5}	3.7×10^{-4}	3.7×10^{-4}	2.6×10^{-4}	5.1×10^{-5}	5.1×10^{-5}	3.7×10^{-5}
Ingestion (Fruit & Vegt.)	4.6×10^{-3}	4.6×10^{-3}	1.4×10^{-3}	5.0×10^{-2}	5.0×10^{-2}	1.5×10^{-2}	6.9×10^{-3}	6.9×10^{-3}	2.0×10^{-3}
Ingestion (Milk)	4.9×10^{-3}	0	2.0×10^{-4}	0	0	0	7.4×10^{-3}	0	2.9×10^{-4}
Groundshine	2.2×10^{-4}	2.2×10^{-4}	2.2×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}
Total	9.8×10^{-3}	4.9×10^{-3}	1.8×10^{-3}	5.3×10^{-2}	5.3×10^{-2}	1.7×10^{-2}	1.5×10^{-2}	7.3×10^{-3}	2.7×10^{-3}

TABLE 5

Table 5.1.2.5b - Critical Group Doses from Particulates

Pathway	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (µSv)			Critical Group Dose (µSv)			Critical Group Dose (µSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Inhalation (^{90}Sr)	1.7×10^{-3}	1.7×10^{-3}	2.2×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	3.7×10^{-3}	1.2×10^{-2}	1.2×10^{-2}	1.5×10^{-2}
Ingestion (^{90}Sr local fruit & Vegt.)	4.5×10^{-2}	4.5×10^{-2}	1.5×10^{-2}	7.6×10^{-2}	7.6×10^{-2}	2.6×10^{-2}	3.1×10^{-1}	3.1×10^{-1}	1.1×10^{-1}
Ingestion (^{90}Sr local milk)	3.0×10^{-2}	0	1.4×10^{-3}	0	0	0	2.1×10^{-1}	0	9.7×10^{-3}
Ingestion (^{137}Cs Fruit & Vegt.)	2.6×10^{-3}	2.6×10^{-3}	6.4×10^{-3}	4.5×10^{-3}	4.5×10^{-3}	1.1×10^{-2}	1.8×10^{-2}	1.8×10^{-2}	4.4×10^{-2}
Ingestion (^{137}Cs local milk)	3.3×10^{-3}	0	1.1×10^{-3}	0	0	0	2.3×10^{-2}	0	7.5×10^{-3}
Groundshine (^{137}Cs)	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	8.2×10^{-2}	8.2×10^{-2}	8.2×10^{-2}
Ingestion (^{134}Cs local fish)	2.4×10^{-3}	2.4×10^{-3}	2.8×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.5×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.5×10^{-3}
Ingestion (^{137}Cs local fish)	8.3×10^{-3}	8.3×10^{-3}	8.3×10^{-2}	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-1}	3.6×10^{-2}	3.6×10^{-2}	3.6×10^{-1}
Total	1.1×10^{-1}	7.2×10^{-2}	1.5×10^{-1}	1.2×10^{-1}	1.2×10^{-2}	1.9×10^{-1}	6.9×10^{-1}	4.6×10^{-1}	6.5×10^{-1}

TABLE 6

Table 5.1.3.1 - Summary of 1993 Critical Group Doses and Comparison with Legal Limits and Background Dose

Nuclide Group	Darlington NGS			Pickering NGS			Bruce NPD		
	Critical Group Dose (μSv)			Critical Group Dose (μSv)			Critical Group Dose (μSv)		
	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult	Infant "A"	Infant "B"	Adult
Noble Gas	1.32	1.32	1.32	9.64	9.64	9.64	2.12	2.12	2.12
Tritium	0.41	0.24	0.36	2.02	2.18	3.32	2.13	2.56	3.03
C^{14}	0.63	0.46	0.39	3.20	3.20	2.53	1.26	1.26	1.04
I^{131}	0.01	0.00	0.00	0.05	0.05	0.02	0.01	0.01	0.00
Particulates	0.11	0.07	0.15	0.12	0.12	0.19	0.69	0.46	0.65
Total	2.47	2.10	2.22	15.03	15.19	15.70	6.22	6.42	6.85
As Percent of Legal Limit (%)	0.05	0.04	0.04	0.3	0.3	0.31	0.12	0.13	0.14
As Percent of Ontario Background Radiation (%)	0.07	0.06	0.06	0.42	0.42	0.44	0.17	0.18	0.19

ATOMIC ENERGY OF CANADA LIMITED SUBMISSION TO THE MOEE ON THE POTENTIAL IMPACT OF REDUCING THE ONTARIO DRINKING WATER OBJECTIVE FOR TRITIUM

1. INTRODUCTION

The International Commission on Radiological Protection has recently recommended changes in maximum radiation dose limits. These recommendations are being assessed by other international bodies and national regulatory agencies to determine the need for changes to guidelines and regulatory limits. The World Health Organization (WHO) has responded by adjusting their recommended limits for the intake of radionuclides. The new WHO recommended limit for tritium in drinking water is 7800 Bq/L on an annual average basis. The MOEE have proposed that the Ontario Drinking Water Objective (ODWO) for tritium be reduced from the current 40,000 Bq/L to 7000 Bq/L.

The proposed new ODWO has been examined by the Advisory Committee on Environmental Standards (ACES). ACES has recommended an interim ODWO of 100 Bq/L that should be implemented immediately followed by a further reduction to 20 Bq/L after five years. ACES recommends that these limits be applied on a peak not to exceed basis rather than the annual average basis, and that alternate drinking water supplies should be provided whenever the limits are exceeded.

This submission provides information on tritium releases, and potential radionuclide release control technologies for AECL operated facilities in the province of Ontario. The information on tritium releases includes summaries of current and past tritium releases, tritium concentration at nearby water supply plants and AECL's response to tritium spills. The information on radionuclide release control technologies includes a description of equipment and actions needed to limit tritium releases to meet ACES recommended ODWO, the estimated costs of the equipment and actions and the impacts of the ACES recommendations on the control of other radionuclide emissions, and AECL operations in general.

2. CURRENT AND PAST EMISSIONS OF TRITIUM FROM AECL OPERATED FACILITIES IN ONTARIO

2.1 Current and Past Tritium Emissions

AECL operates two nuclear facilities in Ontario, the Chalk River Laboratories (CRL) and the Nuclear Power Demonstration (NPD) plant. Both of these facilities are regulated by the Atomic Energy Control Board (AECB).

The NPD plant and CRL are both located on the shores of the Ottawa River in Ontario's Renfrew County. The NPD plant is a partially decommissioned 75 MW (electrical power) CANDU prototype nuclear generating station that last operated in 1986. The CRL site is located approximately 20 km downstream from NPD and has a number of nuclear facilities. The CRL facilities are used for basic and applied research in atomic energy and related technologies (including R&D in support of current and future CANDU reactors), the production of radioisotopes for medical diagnoses and treatment, and radioactive waste management. The largest facility is the 135 MW (thermal power) NRU research reactor.

The AECB approved emission limits for radionuclides from these facilities, known as Derived Release Limits (DRLs), are based on the regulatory limits for radiation dose to members of the public, considering not only drinking water but all significant environmental pathways leading to exposure. The dose limits in turn are based on recommendations and standards of international bodies such as the International Commission on Radiation Protection (ICRP). At present the AECB's regulatory dose limit for members of the public is 0.005 Sievert (Sv) in a year (but this limit is expected to be reduced in the near future to 0.001 Sv in a year in accordance with recent ICRP recommendations). Average doses to Canadians resulting from normal background sources of radiation are about 0.002 to 0.003 Sv per annum.

In the case of liquid emissions, derived release limits (DRLs) are expressed in terms of Becquerels (Bq) per month [Note: 1 Bq = 1 atomic disintegration/second]. Continuous release for an entire year at a rate equal to the DRL could theoretically result in a dose to the most highly exposed group of people equal to the annual dose limit. AECL controls normal operational releases of tritium (and other radionuclides) to a small fraction of the DRLs and consequently a small fraction of the dose limit and of natural exposure.

The annual average releases of tritium from the NPD site to the Ottawa River for the last ten years are shown in Table 2.1, expressed both in terms of TeraBecquerels per month and as a fraction of the DRL. The releases are currently stable at less than 0.1 TBq/month (0.00001% of DRL) and are expected to slowly decrease over time. Annual average and maximum value of the monthly average (based on routine monthly composite samples) concentrations of tritium in Ottawa River water at the intake to the Town of Deep River water treatment plant (the nearest municipal water intake downstream of the NPD plant) during the same period are shown in Table 2.2. Also shown are the corresponding concentrations at Rolphton, upstream of both NPD and the des Joachims hydro-electric dam, representing the background contribution from natural and global (i.e. past atmospheric testing of nuclear weapons by the major superpowers) sources.

Monthly average tritium concentrations at Deep River never exceeded 100 Bq/L during this period, and exceeded 20 Bq/L on average about one month per year. The monthly average has not exceeded 20 Bq/L for the last four years as emissions from NPD decreased. There is no data available on the peak instantaneous tritium concentrations at the Deep River Water Supply Plant.

Annual average and maximum value of the monthly average (based on routine monthly composite samples) tritium releases from the CRL site to the Ottawa River for the past ten years are shown in Table 2.3, expressed as TeraBecquerels per month and as a fraction of the DRL. Table 2.4 shows annual average, and maximum value of the monthly average tritium concentrations in Ottawa River water at the City of Pembroke water treatment plant intake, downstream of CRL, along with corresponding concentrations at Deep River (upstream of CRL) and Rolphton representing the contribution from other sources. Table 2.4 also shows peak (instantaneous) tritium concentrations at the Pembroke and Petawawa (nearest downstream municipal intake) based on special sampling following two abnormal release incidents at CRL.

Tritium emissions from CRL during this period have always been a small fraction of the DRL, the maximum value of the monthly release being 1.3% of the DRL. Tritium concentrations were always well below the existing tritium ODWO of 40,000 Bq/L at downstream intakes during the period, the maximum short term concentration being 1150 Bq/L. These peak concentrations do not represent an increased potential for adverse affects since radiation dose is accumulated over time. It is the integrated, or average exposure over time, that determines dose. The monthly average concentration at Pembroke exceeded 100 Bq/L on two occasions, and exceeded 20 Bq/L on average 2.4 months per year with the frequency decreasing in recent years. The total population exposure resulting from these releases is expected to be less than 0.3 person Sv per annum. Since tritium is radioactive it will decay of its own accord in the environment. The decay product is helium-3, which is not radioactive. The half-life of tritium, which is the time for half the original quantity to decay, is 12.3 years.

2.2 Sources of Tritium at AECL Facilities

Tritium is a radioactive isotope of the hydrogen atom (atomic mass 3 instead of normal 1), produced in nuclear reactors as an unavoidable result of neutron activation of heavy water. Water naturally contains about 0.02% heavy water molecules. As in CANDU reactors, use of water which is highly enriched in heavy water (>99.75%) as a neutron moderator and/or coolant is an essential component of the design of the NPD reactor and the research reactors at CRL .

Tritium concentrations in the NRU reactor heavy water can range up to about 0.7 TBq/L (TeraBecquerels per litre).

NOTE: 1 TBq = 1×10^{12} Bq
1 TBq = 0.003 g of tritium (hydrogen-3) atoms
= 0.02 g of tritiated water (HTO) molecules

Average tritium emissions in CRL liquid effluents during the past ten years (Figure 2.3) are equivalent to about 24 L of heavy water per month at this concentration, and represent about 0.3 grams per month of pure tritiated water (i.e. water molecules containing one tritium atom in place of a normal hydrogen atom).

Tritium in liquid effluents from AECL sites is in the form of water molecules, and is therefore not removable by any conventional wastewater treatment technologies. AECL's facilities are designed and operated to keep losses of heavy water as low as reasonably achievable in order to minimize tritium emissions to the environment, radiation doses to operating personnel in the facilities, and economic losses (current cost of reactor grade heavy water is about $400/kg).

Tritium releases occur as a result of minor leakage and spillage during normal operation and maintenance. Occasionally somewhat larger releases occur as a result of equipment failures such as failures of heat exchangers, or piping failures. Where practical, leakage or spillage is collected and recovered. The material which cannot be recovered is discharged directly or indirectly in various waste streams. In the case of heat exchanger leaks or failures, losses may occur by way of the secondary cooling water effluent.

As noted in Section 2.1 above, the NPD reactor has been shutdown since 1986 and is partially decommissioned. It no longer represents a significant source.

At CRL the main source of past and present tritium emissions is the NRU research reactor, which is cooled and moderated with heavy water. Minor leakage and/or spillage may occur from pump seals, valves, and other heavy water system components system during normal operation and maintenance. Small unavoidable losses may also occur during fuelling operations with the fuelling machine, particularly during almost daily removal of targets for production of medical radioisotopes.

The peak release from CRL during 1988 (Tables 2.3 and 2.4) was the result of failure of a heavy water pump in NRU. Although most of the spilled heavy water was collected and recovered for upgrading, a fraction was released directly as a result of a previously unrecognized release route, and some indirectly as wastewater that was downgraded below the practical limits for recovery and upgrading.

A second significant source of past tritium emissions from CRL was the NRX research reactor, which was heavy water moderated but employed light (natural) water for fuel cooling. NRX has been shutdown since 1992 and is to be decommissioned; it is no longer a significant source.

A third significant source at CRL is the Heavy Water Upgrading Plant. This facility employs an electrolysis process to restore recovered and downgraded heavy water to reactor grade for reuse. Minor emissions occur as a result of minor leakage and spillage, and as residual tritium in waste light water after completion of the upgrading process to the practical limits of recovery. A heat exchanger failure in the Heavy Water Upgrading Plant resulted in the larger than normal release in 1991 indicated in Tables 2.3 and 2.4.

Other sources of CRL tritium emissions include: some in-ground waste management facilities which receive (or received in the past) tritiated waste from other CRL facilities (since tritium is essentially water, it will move with the groundwater); and the tritium research laboratories which carry out research and development on tritium technologies and safety in support of CANDU reactors and nuclear fusion research.

2.3 Current Response and Cost of Tritium Spills

AECL facilities are designed to contains spills of water containing tritium. Small heavy water spills are typically cleaned up manually, and absorbent materials (eg. cloths, mops) used in the cleanup may be dried in a heavy water recovery unit if practical.

In the case of large heavy water spills inside a facility, the water would typically collect in sumps, from where it would be pumped into drums for cleanup and upgrading in the CRL Heavy Water Upgrading Plant (see Section 2.2). Large spills of heavy water with high tritium levels may create a health hazard to personnel within the facility and/or involved in the cleanup due to the presence of high concentrations of tritiated water vapour in the air within the facility and the possibility of personnel being splashed. As a result such operations typically require protective clothing and a supply of clean breathing air. Such an event would typically be considered a reportable event and would be promptly reported to the Atomic Energy Control Board (AECB), and would trigger a formal investigation of the event resulting in recommendations for preventing similar occurrences in future.

If a spill results in a large release of tritium from the facility the incident would be promptly reported to the AECB, and to Federal and Provincial Environment Ministries. If appropriate, officials in neighbouring communities would be notified. Special environmental monitoring to determine/confirm the potential impacts on and off the site would be implemented. As above, a formal investigation would be conducted after the event.

The cost of a tritium (i.e. heavy water) spill is not easily determined. The obvious direct cost is the replacement cost of the lost heavy water: for a spill resulting in a loss in the order of several hundred litres at current heavy water prices this could be in the range of $200,000 to $300,000. If a large quantity of spilled heavy water is also collected and recovered from building sumps, the cost of upgrading it could be comparable. Other costs would include the cost of special environmental monitoring, the cost of the investigation of the incident, and the cost of any system repairs and modifications to prevent occurrence; these costs could range from some 10's to 100's of thousands.

2.4 Other Programs That May Affect Tritium Emissions

There are no external programs and initiatives that are likely to have any significant effect on tritium emissions in the foreseeable future. A reduction in the AECB's regulatory dose limits in response to recent ICRP recommendations is anticipated, but emissions are well below these limits.

3. TECHNOLOGIES, PROCEDURES AND COSTS OF CONTROLLING TRITIUM RELEASES TO OTTAWA RIVER

The facilities at CRL have been designed to minimize the release of tritium within the practical constraints of the technology available at the time of their construction. One of the motives for this minimization of tritium releases is the need to minimize the associated loss of heavy water which costs about \$400/kg. As a result of these efforts, the annual dose to the most highly exposed members of the public resulting from liquid emissions of tritium is estimated to average about 0.06% of the public dose limit, or only about 0.1% of the normal background radiation dose to Canadians. Another consequence, is that further reductions in tritium releases can only be achieved using non-conventional technology that is very expensive.

The data presented in Section 2 indicates that tritium releases from CRL and NPD combined with background tritium have been such that the average tritium concentration at the Pembroke Water Supply Plant has been below 41 Bq/L for the past ten years. The average annual concentration of tritium exceeded 20 Bq/L in four of the past ten years. The maximum short term tritium concentrations at downstream water supply plants over the last ten years was 1150 Bq/L.

The tritium concentrations at the downstream water supply plant intakes could be maintained below the 100 Bq/L recommended by ACES by installing equipment to reliably retain tritiated heavy water that is released due to equipment faults or other process upsets. This retained water would then be later released in a controlled manner so as not to exceed the 100 Bq/L limit. The two facilities at CRL that contain significant quantities of tritiated heavy water in process equipment are the NRU research reactor and the heavy water upgrader. The following equipment would be required to retain tritiated heavy water released during process upsets in these facilities.

Description of Equipment		Expected Cost
1.	Dedicated radioactive drain system for heavy water processes (drain system to have large catch tanks to retain and temporarily store released heavy water).	$10,000,000
2.	Continuous tritium monitoring and leak detection on all individual sources of tritium.	$3,000,000
3.	Secondary heat transfer loop on all heavy water heat exchangers.	$50,000,000
4.	Heavy water process equipment redundancy	$20,000,000
5.	Increased maintenance costs due to the need to replace heavy water process equipment as soon as minor leaks develop.	$1,000,000/year
Total - Process Upset and Recovery Costs		~$80,000,000 initially plus $1,000,000/year thereafter

It should be noted that the above equipment would not reduce the tritium released to the river. It would only stretch out the duration of the releases so as to prevent peak concentrations at downstream water supply plants from exceeding 100 Bq/L. The reason for releasing the retained water to the river is that it is very difficult to recover heavy water or tritium that is highly diluted in ordinary water. This is explained further in the following paragraphs.

ACES has also recommended a further reduction of tritium emissions to 20 Bq/L within five years. This reduction could only be achieved by removing the tritium from recovered water prior to releasing it to the river. It will also be necessary to limit the tritium released from the CRL waste management areas.

Tritium cannot be removed from water by using technologies that are used for removing chemical contaminants. Tritiated water has the same chemical properties as ordinary water and it can only be separated from ordinary water using isotope separation technologies. These technologies are generally much more expensive than chemical contaminant removal technologies. Most of the isotope separation technologies that are available cannot process relatively large volumes of water and achieve the very low tritium concentrations needed in the treated output. Vacuum distillation is the only feasible method identified for meeting this requirement. The estimated volume of recovered tritium contaminated water is 15,000 m^3/a. Two 1,000 kg/hr vacuum distillation units would be required to process this water. The estimated cost of the vacuum distillation plant is $67,000,000.

A reduction of tritium releases from the waste management areas can be achieved by diverting all waste having significant tritium content from the sand trench facility to concrete bunkers and subsequent disposal in an Intrusion Resistance Underground Structure (IRUS) facility. The costs of diverting 1,000 m^3/year of tritium contaminated waste from sand trench to concrete bunker and IRUS are estimated to be $6,000,000 per year.

The costs of reducing the tritium concentrations at downstream water supply plants to 20 Bq/L are summarized below:

Description of Equipment		Expected Cost
1.	Process Upset Recovery Equipment (see previous table for details)	~$80,000,000 plus $1,000,000/year
2.	Vacuum distillation plant (2000 kg/hr capacity)	$67,000,000
3.	Diversion of all tritium contaminated waste to concrete bunker and IRUS disposal	$6,000,000/year
Total - Tritium Recover, Extraction and Storage Costs		~$150,000,000 initially plus $7,000,000/year thereafter

The tritium concentrations at the Deep River Water Supply Plant are now continuously below 20 Bq/L, therefore no actions would be required to reduce releases at NPD.

ACES also recommends a long-term objective of reducing tritium in drinking water to natural background levels. This objective is unlikely to be achieved at any cost by further use of tritium recovery and extraction technologies. The only method of achieving this objective would be to eliminate the use of heavy water reactor technology which is not consistent with AECL's mission.

Most of the costs associated with the release control strategies described above are brought about by the ACES requirement to control tritium on a not to exceed peak concentration basis. This departs from international practice of controlling long-term radiation exposures on a time average basis. If one were to apply the ACES recommended immediate reduction to 100 Bq/L on an annual average basis, the limit could be currently met at water supply plants downstream of both NPD and CRL. The 20 Bq/L limit applied on an annual average basis could be currently met at Deep River (downstream of NPD) and could probably be met downstream of CRL with some additional, recovery control and intervention measures at CRL. Although specific measures have not been identified, the cost is probably equal or less than the $80,000,000 for recovery and control measures estimated for compliance with 100 Bq/L peak not to exceed the limit.

4. IMPACT OF APPLYING ACES METHODOLOGY TO OTHER RADIONUCLIDES AND PUBLIC EXPOSURE PATHWAYS

The previous section deals only with drinking water exposures from tritium, which is the information requested by the MOEE [2]. However, ACES have proposed a new methodology for regulating radionuclides that, if accepted for tritium, could ultimately be applied to other radionuclides to maintain consistent rationale for the protection of public health. The ACES recommendations to reduce the ODWO for tritium to 100 Bq/L immediately and 20 Bq/L in 5 years corresponds to annual radiation doses through this pathway of about 0.0000014 Sievert (Sv) and 0.00000029 Sv respectively (compared to normal dose to all Canadians from background sources of about 0.002 to 0.003 Sv per annum). The 20 Bq/L recommended by ACES is based on a hypothetical lifetime risk of fatal cancer of one in one million assuming a linear dose response from observed effects at high dose levels. Since the potential health effects from exposure to tritium are no different than for other nuclides, the public would expect consistent regulations for all exposures.

In addition, ACES has recommended that a multimedia approach be used in establishing tritium standards. Once again a similar approach for other radionuclides would be expected. Present nuclear facility emission limits (Derived Release Limits or DRLs - see Section 2.1) do consider all significant environmental pathways leading to exposure (e.g. drinking water, inhalation, foods, external exposure to clouds and contaminated ground), and are based on the current AECB annual dose limit of 0.005 Sievert. Applying the 2.9 x 10^{-7} Sv annual dose equivalent for the 20 Bq/L of tritium in drinking water to other radionuclides and pathways results in a reduction factor of 17,500 in the CRL release limits.

The impact of applying the ACES methodology to other radionuclides and pathways has been assessed by comparing average CRL emissions of tritium and other significant radionuclides for the past five years to DRL values reduced by the above factor. This approximates achieving a 2.9 x 10^{-7} Sv dose from the air and water emission of each affected radionuclide considering all exposure pathways. Results, which look only at average values rather than maximum values, and do not consider normal background concentrations of some of these radionuclides, are shown in Table 4.1. As can be seen from these tables, substantial reductions would be required for a number of radionuclides to achieve the dose per radionuclide of 2.9 x 10^{-7} Sv equivalent to the ACES criteria for tritium in drinking water. If normal background concentrations of these radionuclides were included then it may be impossible to meet the ACES criteria, since the background concentration of some nuclides are a substantial fraction of the ACES values.

The large reductions required to meet the ACES criteria for all radionuclides would require major changes in technologies and operations at CRL. It has not been possible in the timeframe available to confirm or identify specific technologies needed to meet the ACES criteria for each radionuclide. However, the release characteristics of existing CRL facilities have been reviewed to give an indication of the magnitude of the investments that would be required.

A major reduction (factor of 280) would be required in the release of noble gases. The major source of noble gases is the air cooling of the NRU reactor thermal column. This air cooling is a fundamental aspect of the NRU design. There is no practical method of eliminating the air cooling or substantially reducing the noble gases produced by air cooling. There is no practical technology that can achieve the required noble gas removal efficiency for the 12,000 CFM of NRU air effluent. The only way to achieve the required reduction in emission would be to replace NRU with a reactor having a different design. This new reactor would have to be designed at a conceptual stage to achieve the ACES emission criteria.

The cost of replacing NRU with a low emission reactor having the same capabilities as NRU would be very expensive. It would be in excess of $1,000,000,000 and quite possibly in excess of $2,000,000,000. Due to the high cost, AECL does not anticipate that it would be viable to replace NRU with a low emission general purpose research reactor of equal capability. Another option might be to replace the general purpose NRU reactor with two more specialized low emission reactors, one for radioisotopes and the other for research. Although the cost would be less, it would still likely exceed $700,000,000 with the low emission technology, and there would be a loss in capability over what is currently available with NRU.

Another source of airborne noble gas emissions is the radioisotope processing cells. These cells are used primarily to extract Molybdenum-99 (Mo-99) from targets that are irradiated in the NRU reactor. The Mo-99 is the source of Technetium-99m which is used worldwide for medical diagnostic purposes. Reduction in cell emissions would likely require a significant re-design of the cells and processing equipment plus new delay columns and a cryogenic extraction system to retain noble gases. The cost of this equipment is estimated to be $30,000,000.

TABLE 7 - FACTORS REQUIRED TO REDUCE 1993 EMISSIONS TO LEVELS EQUIVALENT TO 5E-6 AND 1E-6 RISK

PAGE 1 of 3

	Darlington			Pickering			BNPD		
	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk
NOBLE GASES	1.3	NA	4,5	9.6	6.7	34	2.1	1.5	7
TRITIUM TOTAL	0.4			3.3			3.0		
Inhalation	0.24	NA	NA	2.6	1.8	9	1.7	1.2	6
Water Ingestion	0.03	NA	NA	0.17	NA	NA	0.8	NA	2.8
Milk Ingestion	0.19	NA	NA	0.0	NA	NA	0.3	NA	NA
Fruit & Vegetable Ingestion	0.09	NA	NA	0.73	NA	2.6	0.9	NA	3.1
Fish Ingestion	0.0009	NA	NA	0.006	NA	NA	0.07	NA	NA

* "RF" = Reduction Factor

1. Lifetime risk of 5E-6 corresponds to an annual dose of 1.43 uSv (over 70 years).
2. Lifetime risk of 1E-6 corresponds to an annual dose of 0.29 uSv (over 70 years).
3. Dose values entered are the maximum of Infant "A", Infant "B" or Adult for each Radionuclide/Pathway, taken from Tables 5.1.2.1b, 5.1.2.2b, 5.1.2.3b, 5.1.2.4b, 5.1.2.5b and 5.1.3.1 from Ontario Hydro's Annual Summary and Assessment of Environmental Radiological Data for 1993, J.R. LaMarre, N-03419-940035-POUO, April 29, 1994.

TABLE 7 - FACTORS REQUIRED TO REDUCE 1993 EMISSIONS TO LEVELS EQUIVALENT TO 5E-6 AND 1E-6 RISK

PAGE 2 of 3

	Darlington			Pickering			BNPD		
	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk
CARBON-14 TOTAL	0.6			3.2			1.3		
Milk Ingestion	0.17	NA	NA	0	NA	NA	0	NA	NA
Fruit & Vegetable Ingestion	0.46	NA	1.6	3.2	2.2	11	1.2	NA	4.2
Fish Ingestion	0.016	NA	NA	0.021	NA	NA	0.07	NA	NA
IODINE-131 TOTAL	0.01			0.05			0.02		
Inhalation	3.4E-5	NA	NA	3.7E-4	NA	NA	5E-5	NA	NA
Fruit & Vegetable Ingestion	4.6E-3	NA	NA	5E-2	NA	NA	7E-3	NA	NA
Milk Ingestion	4.9E-3	NA	NA	0	NA	NA	7E-3	NA	NA
Groundshine	2.2E-4	NA	NA	2.3E-3	NA	NA	3E-4	NA	NA

* "RF" = Reduction Factor

1. Lifetime risk of 5E-6 corresponds to an annual dose of 1.43 uSv (over 70 years).
2. Lifetime risk of 1E-6 corresponds to an annual dose of 0.29 uSv (over 70 years).
3. Dose values entered are the maximum of Infant "A", Infant "B" or Adult for each Radionuclide/Pathway, taken from Tables 5.1.2.1b, 5.1.2.2b, 5.1.2.3b, 5.1.2.4b, 5.1.2.5b and 5.1.3.1 from Ontario Hydro's Annual Summary and Assessment of Environmental Radiological Data for 1993, J.R. LaMarre, N-03419-940035-POUO, April 29, 1994.

TABLE 7 - FACTORS REQUIRED TO REDUCE 1993 EMISSIONS TO LEVELS EQUIVALENT TO 5E-6 AND 1E-6 RISK

PAGE 3 of 3

	Darlington			Pickering			BNPD		
	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk	Dose (uSv)	RF for 5E-6 risk	RF for 1E-6 risk
PARTICULATES TOTAL	0.15			0.19			0.69		
Inhalation	0.002	NA	NA	0.004	NA	NA	0.015	NA	NA
Fruit & Vegetables Ingestion (Sr-90)	0.045	NA	NA	0.076	NA	NA	0.31	NA	1.1
Milk Ingestion (Sr-90)	0.03	NA	NA	0	NA	NA	0.21	NA	NA
Fruit & Vegetables Ingestion (Cs-137)	0.006	NA	NA	0.01	NA	NA	0.04	NA	NA
Milk Ingestion (Cs-137)	0.003	NA	NA	0	NA	NA	0.02	NA	NA
Groundshine (Cs-137)	0.012	NA	NA	0.02	NA	NA	0.08	NA	NA
Fish Ingestion(Cs-134)	0.03	NA	NA	0.03	NA	NA	0.03	NA	NA
Fish Ingestion(Cs-137)	0.08	NA	NA	0.1	NA	NA	0.36	NA	1.2

* "RF" = Reduction Factor

1. Lifetime risk of 5E-6 corresponds to an annual dose of 1.43 uSv (over 70 years).
2. Lifetime risk of 1E-6 corresponds to an annual dose of 0.29 uSv (over 70 years).
3. Dose values entered are the maximum of Infant "A", Infant "B" or Adult for each Radionuclide/Pathway, taken from Tables 5.1.2.1b, 5.1.2.2b, 5.1.2.3b, 5.1.2.4b, 5.1.2.5b and 5.1.3.1 from Ontario Hydro's Annual Summary and Assessment of Environmental Radiological Data for 1993, J.R. LaMarre, N-03419-940035-POUO, April 29, 1994.

TABLE 8

IMPACT OF APPLYING 5E-6 OR 1E-6 RISK LIMITS TO ALL ONTARIO HYDRO RADIOACTIVE EMISSIONS

BASED ONLY ON 1993 DATA

Radionuclide/ Emission Pathway	(S)ingle or (M)ultiple Pathway	Emission Reduction Factor Required for Risk = 5E-6			Emission Reduction Factor Required for Risk = 1E-6		
		DNGS	PNGS	BNPD	DNGS	PNGS	BNPD
Noble Gas/air	S	NA	6.7	1.5	4.5	34	7
C-14/AIR	S	NA	2.2	NA	1.6	11	4
H-3/AIR	S	NA	1.8	1.2	NA	9	6
H-3/WATER	S	NA	NA	NA	NA	NA	2.8
PARTICULATE/AIR	S	NA	NA	NA	NA	NA	1.1
PARTICULATE/WATER	S	NA	NA	NA	NA	NA	1.2
Noble Gas	M	NA	6.7	1.5	4.6	34	7
C-14	M	NA	2.2	NA	2.2	11	4.4
H-3	M	NA	2.3	2.1	1.4	12	10.4
PARTICULATE	M	NA	NA	NA	NA	NA	2.4

Note: The above factors assume that background radioactivity is not included.
If background is included (as required for drinking water), these factors will increase.

For C-14, the natural background level of about 250 Bq/kg-C already exceeds the maximum concentration that would be allowed for a lifetime risk level of 5E-6 for milk, fruits and vegetables. For the risk level of 1E-6, natural background would exceed the maximum concentrations for milk, fruits, vegetables and fish.

TABLE 9

COST OF REMOVING TRITIUM VAPOUR FROM STATION VENTILATION EXHAUST AIR

Example: Bruce NGS-A

Ventilation Path	Flow (scfm)	Capital Cost, M$	Operating & maint. cost, M$
Reactor Auxiliary Bay	60,000	0*	0*
Service Building	95,000	31	0.42
Irradiated Fuel Bay	60,000	19	0.27
Ancillary Services Building	45,000	14	0.2
TOTAL		64	0.9

* Assumed reactor building exhaust was already dried sufficiently.

TABLE 10

CALCULATIONS FOR CARBON-14 CONCENTRATIONS BASED ON RISK LEVELS

		Risk = 5E-6*	Risk = 1E-6*
Drinking Water	adult	3.97 Bq/L	0.8 Bq/L
	infant	2.98 Bq/L	0.6 Bq/L
Inhalation	adult	33.2 Bq/m3	6.6 Bq/m3
	infant	68.1 Bq/m3	13.6 Bq/L
Vegetation	adult	13 Bq/kg	2.6 Bq/kg
	infant	217 Bq/kg-C	43 Bq/kg-C
Aquatic Food	adult	143Bq/kg 1144 Bq/kg-C	28.6 Bq/kg 228 Bq/kg-C
	infant	446 Bq/kg 3568 Bq/kg-C	89 Bq/kg 712 Bq/kg-C
Milk	infant	2.4 Bq/kg 36.4 Bq/kg-C	0.48 Nq/kg 7.3 Bq/kg-C

* Concentration Calculations are based on 5E-6/Sv and 1E-6/Sv for lifetime of 70 years.

Natural Background carbon-14 concentration is 250 Bq/kg-C.

The ACES criteria for regulating radionuclides would also have a major impact on the technologies used for disposal of low and intermediate level radioactive wastes. AECL has waste management facilities for wastes generated at CRL as well as radioactive wastes generated at hospitals and universities across Canada. CRL is the only site in Canada that has facilities to handle these wastes. These waste management services are essential for the continuation of nuclear medicine in Canada and research at universities using radionuclides.

AECL has developed the IRUS technology and is developing the Improved Sand Trench (IST) for waste disposal based on AECB regulatory policy R-104. This policy requires an assessment of impacts well into the future. The assessment is based on a maximum annual dose of 5×10^{-5} Sv which the AECB considers to be a de minimus risk. The application of the ACES criteria to future exposure scenarios would result in the diversion of a large portion of the wastes currently slated for IRUS and IST to deep geological repository disposal. It is estimated that 15,000 m^3 of current waste would be affected plus an additional 2,000 m^3 per year hereafter. The associated increases in cost are estimated to be $4,000,000,000 for existing waste and $500,000,000 per year for future wastes.

5. CONCLUSION

Over the past five years, the tritium levels at Deep River and Pembroke have normally been around 4 to 15 Bq/L and 8 to 120 Bq/L respectively. There are occasions where higher concentrations are experienced for a relatively short duration. These events are usually due to equipment failures or leaks and they result in tritium concentrations of up to 1150 Bq/L at Pembroke. There have been at least two occasions over the past ten years where tritium concentrations are known to have exceeded 100 Bq/L at Pembroke. It is expected that tritium concentrations would frequently exceed 20 Bq/L at the Pembroke and Petawawa Water Supply Plants, however the frequency of these events cannot be determined from the existing CRL time averaged release data.

The impact of complying with the ACES recommendations for tritium would be very large. The direct costs of complying with the 100 Bq/L limit would be $80,000,000 initially plus $1,000,000 per year thereafter with no significant reduction in the total tritium released to the river. The direct costs of complying with the 20 Bq/L limit would be $150,000,000 initially and $7,000,000 annually thereafter. The impact of complying with a modified version of the ACES limits, based on annual average concentrations in lieu of not to exceed concentrations has also been examined. No direct costs were identified for meeting the 100 Bq/L limit on an annual average basis and the cost of meeting the 20 Bq/L limit on an annual average basis is expected to be less than $80,000,000. Although, there are no direct costs of meeting the 100 Bq/L limit on an annual average basis, the eventual total costs of meeting this limit and all of the above limits is expected to be very large as explained below.

The MOEE requests for information [2], only addresses the impact of the ACES recommendations on controlling tritium in drinking water. ACES, however, have recommended a new methodology for regulating radionuclides. If this methodology was to be adopted for regulating tritium in drinking water, it is inconceivable that it would not also be applied to each radionuclide and exposure pathway. The potential impacts of exposures from other radionuclides and pathways is no different than for tritium in drinking water, and the public would expect consistent regulations for all exposures. The impacts of applying the ACES methodology to other nuclides and exposure pathways is very large. It would require major modifications or outright replacement of every major nuclear facility at CRL. The technologies required to conform to the ACES methodology have not been identified. However, the costs would likely be in the many billions of dollars.

In summary, the costs of adopting the limits recommended by ACES will be very large, and is expected to be in the many billions of dollars when considering the inevitable application of the ACES methodology to other radionuclide exposures and pathways. However, focusing on the cost alone does not provide a complete assessment of the ultimate impacts. The end result of these costs is that a number of socially desirable activities will become economically unviable. The production of medical radioisotopes and research into improved safety features for nuclear power reactors are two activities that are sensitive to costs. The production of medical radioisotopes would be drastically curtailed or eliminated altogether as a result of cost increases. AECL's CRL site currently supplies more than 80% of the world demand for Mo-99, a radioisotope that is used in 12,000,000 medical diagnostic procedures per year. Apart from CRL, there are no other sites that can currently produce these radioisotopes, reliably, in the required quantities to meet world demand. Other activities that would be affected are basic and applied research that contribute to enhancing quality of life in Canada. In contrast to these costs and social impacts the benefits to be gained from the reduced tritium emissions are expected to be very low or nonexistent.

6. REFERENCES

[1] ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, 1991.

[2] Gaghador, Rohan, MOEE, letter to Norman Gentner, AECL, 1994 July 26.

[3] Killey, R.W.D., AECL, Radionuclide Releases from and Environmental Impacts of the Nuclear Power Demonstration Reactor at Rolphton, Ontario, 1989 November.

[4] AECL, Annual Safety Report Series, ASRA-7 to 13, 1984 - 1990.

[5] AECL, Annual Report of Radiological Monitoring Results for the Chalk River and Whiteshell Laboratory Sites, Volume 2 - Effluent Monitoring, 1990 - 1993.

[6] AECL, Annual Report of Radiological Monitoring Results for the Chalk River and Whiteshell Laboratory Sites, Volume 3 - Environmental Monitoring, 1990 - 1993.

[7] AECL, Environmental Protection Branch, Summary of Monthly Environmental Monitoring Results, 1984 January to 1993 December.

Table 2.1
Annual NPD Tritium Discharges

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Average Annual Release Rate (Bq/s)	8.16E+06	4.62E+06	2.58E+06	2.45E+06	1.24E+04	2.29E+04	4.50E+04	3.22E+04	3.62E+04	3.09E+04
Fraction of DRL	0.0023	0.0013	0.00072	0.00068	0.000008	0.000006	0.000013	0.000009	0.000010	0.000009

[References 3, 4, 5]

Table 2.2
Contribution of NPD to Tritium in Ottawa River

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Annual Monthly Avg. Concentration (Bq/L) @ Rolphton @ Deep River	 9.0 14.7	 9.5 11.7	 7.2 8.8	 8.6 16.5	 8.7 11.2	 9.2 10.0	 5.7 5.6	 5.8 5.9	 4.4 5.2	 4.9 6.3
NPD Contribution (Bq/L)	5.7	2.2	1.6	7.9	2.5	0.8	-0.1	0.1	0.8	1.4
Deep River Monthly Maximum (Bq/L)	34.2	29.0	12.5	54.0	30.0	29.0	8.0	9.0	8.3	9.7

[References 6, 7]

Table 2.3
Annual CRL Tritium Discharges

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Average Annual Release Rate (Bq/s)	4.70E+06	5.58E+06	7.20E+06	3.88E+06	1.66E+07	4.44E+06	5.44E+06	9.22E+06	3.76E+06	2.74E+06
Fraction of DRL	0.00042	0.00049	0.00064	0.00034	0.00147	0.00039	0.00048	0.00082	0.00033	0.00024

Table 2.4
Contribution of CRL to Tritium in the Ottawa River

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Annual Monthly Avg. Concentration (Bq/L)										
@ Deep River	14.7	11.7	8.8	16.5	11.2	10.0	5.6	5.9	5.2	6.3
@ Pembroke	19.3	19.4	20.9	23.7	40.6	14.2	16.4	22.3	10.9	8.8
CRL Contribution (Bq/L)	4.6	7.7	12.1	7.2	29.4	4.2	10.8	16.4	5.7	2.5
Pembroke Monthly Maximum (Bq/L)	34.2	29.0	12.5	54.0	30.0	29.0	8.0	9.0	8.3	9.7
Peak Downstream Concentrations										
@ Petawawa	N/A	N/A	N/A	N/A	1150	N/A	N/A	498	N/A	N/A
@ Pembroke	N/A	N/A	N/A	N/A	920	N/A	N/A	386	N/A	N/A

[References 4, 5, 6, 7]

Table 4.1
Impact of ACES Recommendation on all Radionuclides and Pathways

Nuclide	Average Annual Release Rate (Bq/s)	Fraction of Current DRL	Fraction of 20 Bq/L Equivalent Dose[1]
Airborne:			
Noble Gases	2.09E+07	0.0162	280
Tritium	2.91E+05	0.0008	14
I-131	5.42E+00	0.0008	14
I-125	5.58E+00	0.0013	23
Beta/Gamma Particulates	6.56E-02	0.0000	0.02
Liquid:			
Tritium	4.22E+06	0.00458	79.1
Sr-90	4.18E+02	0.00009	1.6
Cs-137	1.11E+02	0.00039	6.8
As-76	7.38E+03	0.00106	19.3
Na-24	4.41E+04	0.00063	10.9
Co-60	1.17E+02	0.00084	14.5

[Reference 5]

notes:

1 - reduction needed in current emissions to meet a dose limit similar to that for tritium at 20 Bq/L

APPENDIX D

Stakeholders and Their Response to an Exceedence of a MAC

Reactions and Administrative Responses by Various Agencies to an Exceedence

A number of stakeholders are involved in or affected by an exceedence of the ODWO for tritium. This section describes in more detail those stakeholders and the range of responses to an exceedence.

a. Source of Tritium (Ontario Hydro, AECL)

If the source of tritium causes an exceedence of the ODWO, it must

- advise the operators of the local water treatment plant, Ministry of Health, Ministry Of Environment and Energy and Ministry of Labour, Emergency Planning Ontario
- commence modelling to predict contaminant dispersion characteristics to target sampling and other water intakes and plants that might be affected.
- undertake intensive sampling at necessary locations

it may have to:

- cease operations temporarily

b. Operators of Water Treatment Plants

Once notified that an exceedence has occurred, the water treatment plant operators can:

- stop pumping water immediately

Temporarily shutting down water treatment plants is not a technically feasible option. The decrease in pressure resulting from the shut down can cause back pressure -- which may cause contaminated water to seep into the supply system and contaminate the water at the water treatment plant. Furthermore the negative pressure can cause pipes to collapse and damage the water supply system. Also the chlorine residual cannot be maintained without pressure in the system creating health risks from bacteria in the water and requiring water that is in the system already to be flushed out. Finally temporarily shutting down water treatment plants creates a trade off between the risks associated with drinking water with tritium above the MAC (a small risk with a large uncertainty) and fire protection (a large risk with greater certainty). Fire protection must be maintained which is only possible if water pressure is upheld through plant operation.

However, a discussion with the operators of a WTP in Wallaceburg indicated that they often close the WTP. A description of the process is contained in the box below.

Shutdown Of Wallaceburg WTP

The Wallaceburg Water Treatment Plant is located on the St. Clair River. It is located downstream from many industrial plants and as a result has a high frequency of shutdowns due to chemical spills into the river. Depending on the length of the contamination, two type of shutdowns can result as explained below:

i) Short duration (<12 hour) of contamination within water stream (Straights shutdown).

ii) Lengthy duration (>12 hour) of contamination within water stream (Straight shutdown with water conservation measures).

STRAIGHT SHUTDOWN

The WTP shuts down ("straight shutdown") when a toxic chemical has been spilled into the water stream. This type of closure occurs when the duration of the contamination is not expected to last beyond 12 hours, otherwise, a "straight shutdown with water conservation measures" would arise (explained below). A straight shutdown consists of closing the low lift pumps (pumps which draw water out of the river) and the water filtration process. Then the water is monitored to ensure that all contaminated water has bypassed the WTP to ensure that before the lift pumps and filtration process are resumed. No additional costs are incurred during a shutdown because the staff on duty have the capability of performing the shutdown. During the temporary closure, the township receives treated water from the reservoir contained within the WTP.

STRAIGHT SHUTDOWN WITH WATER CONSERVATION MEASURES

This type of closure occurs when the water stream has been contaminated beyond 12 hours. In order to conserve the remaining treated water (in the reservoir) and extend this supply of water, it is generally requested that major industries and the public conserve their water use. When the current supply in the reservoir is not enough to meet public demand, treated water from Sarnia is delivered via trucks to the Wallaceburg WTP. As a result, the filtration process is kept open so that the water from Sarnia may still pass through the process for sediment detection while the lift pumps remain closed as in the above scenario.

The industry responsible for the spill is directly liable for financing the truck rentals. They are also responsible for paying the labour costs associated with the closure. Labour is needed (1 person) to organize the off loading of water from trucks and to monitor how much water is pumped into the WTP. Filtration of the water in the pretreatment settling tank is an automatic process during normal operations. However, during shutdowns the water in the pretreatment tanks has to be pumped manually through the system. Labour is also needed (2 persons) in monitoring and setting up pumps necessary to pump the remaining water (prior to closure) from the pretreatment settling tank through to the filtering process.
In cases where the plant is closed for a prolonged period of time, additional notification is issued by the utility requesting the public to conserve water. This can involve WTP employees distributing flyers door-to-door. The cost of this labour is also paid by the industry at fault.

When reopening the plant, at times, the treated water may possess an odour or taste problem with no associated health risks. In those cases, the industry liable will pay to have bottled water made available to the public and will pay for the employees at the WTP to distribute these bottles. This procedure will continue until the water quality improves. During the entire closure, the industry responsible for the spill, will pay for all the necessary labour at a cost equal to the WTP employees regular wage of $17-$18/hr.

According to the Wallaceburg staff, it is very difficult to determine the cost of shutting down the Wallaceburg WTP because every case and associated costs are considered diverse in composition.

☞ provide an alternative drinking water source
an alternative drinking water source can come from

i. within the distribution system from other plants, intakes and reservoirs.

Very few plants have the ability to draw raw water from multiple sources, given the contamination of one supply. Some smaller plants can draw from wells in emergencies but this option is not available for the water treatment plants of concern.

Treatment plants have varying amounts of reservoir capacity for emergency use. Smaller plants can have a full day's worth of reserve supply, while larger plants may have only several hours.

ii. bottled water

As a rule, people consume two litres of water a day. At a price of $0.50 (OCWA) per litre per person, the expenditure would be $1 per person per day.

An alternative to supplying water to residents is to have potable storage within households. This would eliminate the lag between notification of contaminated water and availability of an alternative water supply and eliminate the cost of delivering water to residents.

c. Ministry of Labour

Once notified the Ministry of Labour will

☞ commence intensive sampling to monitor the levels of tritium in the area.

☞ analyze and report results to Ministry of Environment and Energy, Ontario Clean Water Association and/or the Municipality in charge of operating the WTP in question.

d. End Users (Water drinkers and pharmaceutical and food processors)

End users may

☞ consume water with elevated tritium concentration and bear the risk of cancer and other health effects if no alternative water supply is provided
☞ consume water from alternative source and assume no additional risk of cancer and other health effects

e. Emergency Measures Ontario (EMO)

The aim of the EMO is to coordinate a provincial response in the case of elevated levels of radioactivity in drinking water;

After appropriate notification, the EMO will coordinate an inter-agency response to the release. A coordinating management body with representatives from EMO, MOEE, MOL and OH may

☞ obtain information concerning the magnitude and duration of the release and of relevant meteorological parameters;
☞ arrange for monitoring of water at various locations
☞ request results of modelling of possible effects of the release on drinking water
☞ close off beaches and recreational areas
☞ clear the area of small craft.
☞ in consultation with the Medical Officer of Health and local officials, recommended the closing of intakes at WTPs.
☞ and make other recommendations to ensure public health and safety.

Recommended measures would be implemented by the relevant agency.

Feasible Technologies and Actions that can Reduce Releases of Tritium

The ALW system and major heat exchangers such as the boilers and moderator heat exchangers have been identified by Ontario Hydro as the key sources of tritium emissions.

Active Liquid Waste Management System

The ALW system hold up tanks contain a collection of waste light (ordinary) water contaminated with very small amounts of radioactivity. This waste water comes from a large number of small sources.

1) Option one: Pollution Prevention Studies

One option for reducing the tritium in the ALW system is to undertake a large extensive study and monitoring program to characterize each of the sources and pathways that feeds the ALW system, in the hope that a small number of sources may be identified as the major contributors. It may then be possible to reduce tritium losses from those sources. Such a study would be required at each station because of differences in design and operation. The cost of the study might be about $0.5 million, but further work would be required to produce an estimate. However, it should also be noted that following the ALARA (as low as reasonably achievable) principle, emission source reduction has always been a part of normal operations.

It is unknown if better source characterization upstream of the ALW system would lead to any significant reduction in tritium emissions or what this would cost. This type of data has not been collected to date because it was not needed, i.e. the total amount of tritium collected in ALW from all sources combined is small. It falls well below the operating target of 1% of the maximum AECB release limit. Furthermore, maintenance and housekeeping procedures have always been in place to minimize the loss of D_20 (and thus tritium) , not only to keep emissions low, but also for economic reasons as D_20 is very costly (nominally about $400 per kg).

2) Option 2: Detritiation of Waste Water

Another option is to remove the very low concentration tritium from all the collected waste water in the ALW system before it is released to the lake. The TRF is not suitable for treating large volumes of water with such low tritium concentrations. The only feasible method of removing this tritium is by vacuum distillation. The detritiation factor would be about 1000 to 1. This process is a proven technology and is used at Ontario Hydro for upgrading heavy water that is contaminated with ordinary water.

It is estimated that total ALW volume is about 120,000 m3/y. The largest distillation unit in Ontario Hydro has a feed rate of 1,000 kg/hr. **Thus,** the ALW volume could be handled by about 15 such units. Based on the cost of existing Ontario Hydro equipment, the capital cost of such a distillation process to handle the ALW of all Ontario Hydro nuclear stations would be well over $500 million. Operating costs have not been estimated, but are expected to be many millions of dollars because of the high energy usage required by this system. The total cost of building and operating such detritiation units for all nuclear stations could exceed a billion dollars.

Feasible Technologies and Actions that can Reduce Pulses from Equipment Leaks/Failures

1) Option 1: Improve Leak Detection

One option to minimize tritium emissions from equipment leaks and failures is to improve tritium detection and/or leak detection at appropriate locations in the plant. This would allow the faulty equipment to be located and isolated more quickly, thus reducing the amount of tritium released. At present, PNGS is reviewing their tritium leak detection and response capability for all nuclear process systems discharging @o the lake. A new type of continuous on-line tritium monitor is being tested at PNGS to improve the detection and monitoring of tritium in water. An estimate for the cost of the study and the new tritium monitors is not available at this time.

The cost and effectiveness of implementing other leak detection/response measures will not be known until the PNGS study is completed.

2) Option 2: Improve Inspection and Maintenance

Another option to reduce tritium emissions from equipment leaks is to minimize corrosion and to improve the inspection and maintenance programs for boiler equipment and moderator heat exchangers. Boiler maintenance programs entail more frequent inspection for tube wear and cracking, more frequent boiler cleaning using chemical and water lancing and improving repair procedures using plugging and electrosleeving. More frequent inspection of the moderator heat exchangers could also be a part of this. However, some of these programs have already been implemented and are ongoing.

3) Option 3: Boiler Blowdown Recovery

A third option would apply to the boilers. Tritium which leaks to the light water side of the boilers is released to the lake via boiler blowdown. The boiler blowdown system could be modified so that it is a closed loop system, thus eliminating direct tritium releases to the lake. However, it would result in a buildup of tritium in the boiler/feedwater/steam system. This would likely increase emissions of tritium to air until the tritium in this system could be removed (requires a new vacuum distillation process described above). The cost of modifying the boiler blowdown systems of all nuclear plants has been estimated at about $150 million.

4) Option 4: Closed Loop Cooling for Heat Exchangers

A fourth option for tritium reduction is to provide another layer of containment for heat exchangers, i.e. modify all heat exchangers that are now cooled directly by lake water so that they provide closed loop cooling to the nuclear systems and these closed loop systems are in turn cooled by lake water through additional heat exchangers. Again, without the elimination of primary equipment leaks, such a modification would result in secondary light water systems contaminated with more tritium and would require eventual detritiation via the vacuum distillation process described above.

The cost of modifying all heat exchangers cooled directly by lake water and adding another cooling system for each was not estimated, but would be prohibitively costly if it were even feasible, given the physical constraints of existing plant. Furthermore, this action would require chemicals to condition the closed loop cooling water, introducing a subsequent potential pollution problem.

5) **Option 5: Replace Aging Boilers and Heat Exchangers Sooner Than Currently Planned**

A fifth option to minimize occasional unexpected equipment failures (and thus tritium emissions) would be to replace aging equipment much sooner than currently planned. Considering the cost of major heat exchangers and boilers (hundreds of millions to billions of dollars), this would be a prohibitively costly measure.

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